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PHILLIPS PETROLEUM COMPANY
RESEARCH & DEVELOPMENT REPORT 5806-70

SMOKE ABATEMENT IN GAS-TURBINES

PART IV
EFFECTS OF MANGANESE FUEL ADDITIVE ON DEPOSITS AND HOT CORROSION OF TURBINE-BLADE MATERIALS

FINAL REPORT
(23 SEPTEMBER 1968 TO 23 DECEMBER 1970)
DECEMBER 1970

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BY
L. BAGNETTO
R. M. SCHIRMER
H. T. QUIGG

PREPARED UNDER CONTRACT N00156-67-C-2351
FOR
NAVAL AERONAUTICAL ENGINE DEPARTMENT
DEPARTMENT OF THE NAVY
BY
PHILLIPS PETROLEUM COMPANY
BARTLESVILLE, OKLAHOMA

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Air 604

Research and Development Report 5806-70

PHILLIPS PETROLEUM COMPANY

RESEARCH DIVISION

BARTLESVILLE, OKLAHOMA

SMOKE ABATEMENT IN GAS-TURBINES

Part IV: Effects of Manganese Fuel Additive on Deposits and Hot Corrosion of Turbine-Blade Materials

Final Report

Navy Contract No. N00156-67-C-2351

by

L. Bagnetto, R. M. Schirmer, and H. T. Quigg

December 1970

This report reviewed by:

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Final Report
Naval Aeronautical Engine Department Contract N00156-67-C-2351

SMOKE ABATEMENT IN GAS-TURBINES

Part IV: Effects of Manganese Fuel Additive on Deposits and Hot Corrosion of Turbine-Blade Materials

by

L. Bagnetto, R. M. Schirmer, and H. T. Quigg

S U M M A R Y

This investigation represents the final phase of an overall program on the control of smoke emitted from aviation turbine engines and is concerned specifically with the effects of a manganese-containing additive on a wide variety of turbine-blade materials relative to deposit accumulations and hot-corrosion characteristics.

Specimens of 12 different superalloys and 20 different superalloy-coating systems were exposed in the Phillips Turbine Simulator in separate tests using a JP-5 fuel containing 0.04 weight per cent sulfur and an aliquot sample of this fuel containing 0.1 volume per cent methylcyclopentadienyl-manganese-tricarbonyl (Ethyl CI-2 additive) for comparable periods of time between 5 and 165 hours. All specimens were exposed at 15 atmospheres combustor pressure with gas temperatures and velocity at the specimens cycled from 1000 - 2000 F and 163-275 ft/sec by control of fuel flow to simulate conditions in the turbine section of turbine engines. Sea water was added at a concentration of 1 ppm of sea salt in air to simulate a marine environment. Effects of CI-2 on turbine-blade deposits were estimated from chemical and physical analyses, visual appearances, and statistical analyses of differential weight measurements (mg/cm^2). Methods for evaluating the effects of CI-2 on hot corrosion relied on visual observations, metallographic examinations, and statistical analyses based on measurements of metal weight-loss (mg/cm^2), surface-loss (mils), and maximum penetration of corrosion products (mils).

The effect of CI-2 on hot corrosion was found to depend on superalloy composition, coatings, and exposure time. In general, CI-2 in the fuel tended to increase hot corrosion of bare superalloys, and tended to decrease hot corrosion of coated superalloys.

The use of CI-2 in the fuel seriously increased the weight of deposits on all turbine-blade materials at virtually all periods of exposure.

These data indicate that the use of this additive on a continuous or extended basis could reduce engine performance.

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SMOKE ABATEMENT IN GAS-TURBINES

by

L. Bagnetto, R. M. Schirmer, and H. T. Quigg

1. INTRODUCTION

This final report summarizes the work performed by Phillips Petroleum Company under Contract N00156-67-C-2351 with the Naval Aeronautical Department, Naval Air Propulsion Test Center, Philadelphia, Pennsylvania, from 23 June 1968 to 23 December 1970.

The overall emphasis of this contract was directed toward the problems of smoke emission from aircraft-turbine engines with special emphasis on methods for reducing smoke emission by an additive approach, and the effect of these additives on other important operating parameters. Smoke emission from present-generation aircraft, in addition to contributing to the problem of environmental contamination, is of serious concern to the Military for tactical reasons. For example, aircraft flying at low altitude are readily detectable on the horizon by the smoke plume, which has been described as a "large black ball rolling toward the observer". Thus, there is an urgent need for eliminating smoke to assure the success of such missions.

It is generally recognized that aircraft smoke emission can be controlled by designs that lean-out the primary combustion zone; however, such a solution will require long-term research and development. Because of the urgency for an "immediate" solution, and, since certain additives have been reported to be effective for reducing smoke emission, the additive approach was investigated under this contract.

Previous reports under this contract (References 1 through 6) have been concerned with the relative effectiveness of three organo-metallic additives in a broad range of JP-5 type fuels on smoke suppressancy in aircraft-turbine operations. From these studies it was found that Ethyl CI-2 additive (containing manganese) and Lubrizol 565 additive (containing barium) were indeed highly effective and about equal in smoke-suppressancy characteristics. A third additive, Lubrizol 239 (containing calcium), was also effective but somewhat inferior to the manganese and barium additives. It was also shown from these earlier studies that the additives were most effective at operating conditions ranging between about 10 and 15 atmospheres combustor pressure, and 1500 - 1700 F turbine-inlet temperature. Projection of the data to operating conditions of 25 atmospheres pressure and 2100 F, representing the next step in advanced-engine designs, indicated that smoke-suppressant additives will not be necessary, since at these conditions the amount of smoke surviving the

combustor will be below the threshold of visibility.

In an effort to determine if the barium, calcium, and manganese additives had any detrimental effects on engine durability, studies were made of their effects on transverse flame-radiation characteristics (4)*, and axial (down-stream) flame-radiation characteristics (5). It was observed that the barium additive in JP-5 fuel, at some operating conditions, effected slight (up to 17 per cent) but statistically significant (95 per cent confidence) reductions in transverse flame-radiation intensity; whereas, the manganese additive at identical conditions effected slight (up to 22 per cent) increases in flame-radiation intensity. The effect on downstream flame radiation was complicated by the fact that the radiation from the flame was shielded or "screened-out" by the cooler downstream soot particles. However, when allowances were made for this phenomenon, a slight beneficial effect with the barium additive, and a slight detrimental effect with the manganese additive was also apparent. The use of the calcium additive was not observed to have any significant effect on transverse or axial flame-radiation characteristics.

Of major concern when additives containing metal components are used in aircraft-turbine fuels is the possibility that the additives will decompose leaving solid reaction products to accumulate on critical engine parts. Such deposits are of concern for two important reasons. First, deposits on the turbine blades can alter the blade contour to decrease turbine efficiency and overall engine performance. Secondly, deposits may increase the rate of corrosion of hot-section parts to effect significant decreases in time between overhauls.

The deposit-forming tendencies of the manganese- and barium-type additives have been reported in the literature. Pichtelberger (7) showed that deposits from fuels containing Ethyl CI-2 (Mn) had a detrimental effect on the J65-W-16A engine vaporizing tubes, and its use in the T56-A-7A engine caused excessive deposition in the turbine area resulting in engine performance deterioration. Miller (8) has indicated that in field operations of diesel vehicles, where continuous, high-speed, high-load conditions are prevalent, the use of fuels containing a barium-type smoke-suppressant additive, resulted in heavier-than-usual white deposits on exhaust valves and injectors. Also, deposits scraped off of mufflers of diesel vehicles, operated under similar conditions, were shown by analysis to be primarily a mixture of barium sulfate and carbon. Shayeson (9) observed from endurance studies with a J79-8 engine that an organo-barium compound in JP-5 caused excessive vibration and engine stalling after 2.5 hours of continuous operation. Inspection of the engine components showed heavy deposits in the combustor lines, transition ducts and first-stage turbine buckets. The deposits from the first-stage buckets were found to be γ-phase $BaCO_3$. A similar study with a fuel containing an organo-manganese compound showed no heavy build-up of deposits as observed with the barium additives; however, it was noted that the turbine elements had a thin, dusty, black deposit, which was presumed to be Mn_2O_3.

The effect of barium- and manganese-type additives on hot corrosion has not been reported in the literature to any extensive degree. Quigg and

* Numbers in parentheses designate References in Section 7.

Schirmer (10) observed that under some conditions and at concentrations ten times that recommended for adequate smoke suppression Ethyl CI-2 increased the rate of corrosion of some superalloys.

These observations suggest that smoke-suppressant additives under some conditions of operation can be harmful to engine durability and performance. To gain empirical data on these effects, an exploratory program (6) was conducted to determine the relative effects of the barium and manganese additives in JP-5 fuel on deposits and hot corrosion. Specimens of two nickel-base superalloys, IN-100 and U-500 were exposed under conditions simulating both marine and non-marine environments.

All tests conducted in a marine environment (i.e., in presence of sea salt) resulted in significant (95 per cent confidence) increases in deposits by comparison to tests in the absence of sea salt. In all comparisons the barium additive significantly increased deposits relative to the untreated base fuel. Directionally, the use of Ethyl CI-2 increased deposits relative to the base fuel, but the increase was not statistically significant. The markedly greater amount of deposit obtained with the barium additive was observed from scanning-electron-microscope studies to be associated with the highly adhering structure of compact-fused crusts as contrasted to the porous-crystalline mats observed for the manganese-containing deposits.

In general, Ethyl CI-2 (Mn) had little or no effect on metal loss from the two superalloys tested; however, Lubrizol 565 (Ba) reduced metal loss significantly in most comparisons, which is probably associated with a protective coating resulting from the heavy barium-containing deposits. The mode of attack was not altered perceptibly by residues from the manganese or barium additives. Characteristically, it progressed on a broad front without deep intergranular penetration.

From these tests it was concluded that the heavy deposits resulting from the use of the barium additive would be detrimental to engine performance, and it was recommended that no further work be done with this additive. On the other hand, the merit of Ethyl CI-2 could not be fully assessed from the exploratory study. There was evidence to indicate that both deposit formation and hot-corrosion attack were a function of the superalloy composition. As a consequence, a program was conducted to evaluate the deposit and corrosion characteristics of this additive over a broad range of superalloys and coated-superalloy systems. The design of this program and an analysis of the results are detailed in this report.

2. CONCLUSIONS

Methyl cyclopentadienyl-manganese-tricarbonyl (Ethyl Corporation's CI-2 additive) at a concentration of 0.1 volume per cent in an aviation-turbine fuel had been studied using Phillips 2-inch combustor under realistic aircraft turbine operating conditions in a marine environment to determine its effect on a wide variety of bare and coated superalloys with respect to deposit accumulations and hot corrosion. Effects of CI-2 on deposits were estimated from chemical and physical analyses of the scale, visual appearance of the specimens after exposure, and statistical analyses of differential weight measurements. Estimates of effects on hot corrosion relied on visual observations of test specimens after exposure and removal of surface scale, metallographic examinations, and statistical analyses based on differential measurements of metal-weight-loss, surface-loss, and maximum penetration of corrosion products. Based on the evidence from this study, it is concluded that:

1. The attack by hot corrosion on the bare superalloys advanced on a broad front without deep intergranular penetration for both the neat and the CI-2 treated fuels. The depth of subsurface deterioration appeared to be a function of chromium concentration and was limited to about one mil on the low-chromium (less than 10 per cent) nickel-base alloys, but approached ten mils on the high-chromium (greater than 15 per cent) nickel-base and cobalt-base alloys.

2. The mode of attack on coated superalloys was characterized by aluminum depletion of the outer layer followed by oxide and sulfide penetration of the diffusion zone for both the neat and the CI-2 treated fuels. Penetration of the coatings was not uniform, and the attack appeared to concentrate at localized areas. Once the coating failed, the mode of attack was similar to that observed for the bare superalloys.

3. Although the use of CI-2 had no obvious effect on the overall mode of attack or on the depth of subsurface penetration by corrosion products, there were indications that the manganese additive caused somewhat greater pitting of the specimens resulting in an overall increase in surface roughness.

4. The use of CI-2 in the fuel had an effect on surface-scale composition which appeared to be a function of superalloy composition and whether or not an aluminum-type coating was employed. In general, bare, nickel-base alloys, when exposed to CI-2 in the fuel, resulted in scale compositions rich in the mixed spinel structures of cobalt, nickel, chromium, and aluminum; whereas, bare cobalt-base alloys and all coated alloys resulted in scale compositions rich in manganese-oxide structures Mn_3O_4 and Mn_2O_3.

5. The concentration of sodium sulfate in the surface scale, the presence of which is generally associated with hot corrosion, was not seriously affected by the presence of CI-2 in the fuel.

6. The use of CI-2 in the fuel increased the amount of surface scale on all materials tested at virtually all periods of exposure. Overall, the increases in weight of deposits were statistically significant at the 95 per cent confidence level, and in most comparisons the weights were more than twice the amounts resulting from the neat fuel.

7. From the statistical analyses of the data, the effect of CI-2 on hot corrosion was found to be dependent on superalloy composition, coatings and exposure time. In general, the use of CI-2 had no effect or increased the hot corrosion of bare superalloys, and had no effect or decreased the hot corrosion of coated superalloys. These effects were also corroborated by the visual appearances of the specimens after exposure and removal of the surface scale.

8. A study of methods used during this investigation to evaluate the extent of damage to metal specimens from test exposure indicated that all of them (metal-weight-loss, surface-loss, and maximum penetration of corrosion products) were equally sensitive in recognizing significant effects of CI-2; and, although estimates of the effects for specific superalloys and superalloy-coating systems varied, the methods were in agreement with the finding that CI-2 tends to increase the hot corrosion of bare superalloys and tends to decrease the hot corrosion of coated superalloys.

3. RECOMMENDATIONS

The primary objective of this investigation was to determine what effects the addition of 0.1 volume per cent of Ethyl Corporation's CI-2 additive to an aviation-turbine fuel would have on turbine-blade deposits and hot corrosion. The evidence obtained in this study suggests that superalloys without protective aluminum-type coatings would tend to be less resistant to hot-corrosion attack when CI-2 is present in the fuel; but to the contrary, alloys with aluminum-type coatings would tend to be more resistant. Presumably, the completely opposite effects of CI-2 are related to the presence of manganese or its corrosion products on the surface of the specimens. Accumulations of manganese compounds must somehow enhance the protection of the coated specimens possibly by retarding the rate at which aluminum is depleted from the coating; but, in the absence of an aluminum-type coating somehow tend to accelerate hot-corrosion attack. It is fortuitous that the coated superalloys tend to benefit by the presence of CI-2 with respect to durability, which suggests that the use of CI-2 might be tolerated in applications where the increase in deposit accumulations is of little concern--provided that aluminum-type coatings are employed.

In aircraft-turbine operations, however, the accumulation of deposits is of serious concern, and the results of this study give some insight as to the magnitude of the increases in deposit weights that might be expected from the use of CI-2 in the fuel. For example, after exposing specimens to the fuel containing CI-2 it was observed that, at one or more periods of exposure, 22 of the 32 turbine-blade materials more than doubled the weights of deposits that resulted from exposure to the neat fuel, and the increases were statistically significant at the 95 per cent confidence level. Furthermore, since it was noted that the deposits can flake-off during exposure and cooling-down, it is believed that the ten turbine-blade materials, which showed increases of less than 100 per cent, are also highly susceptible to deposit accumulations.

These considerations lead us to believe that a definite risk would be taken with respect to aircraft-turbine performance if aviation-turbine fuels are treated with the CI-2 additive. In view of this risk we recommend that the CI-2 additive not be used in aviation-turbine fuels on a continuous- or extended-use basis. This recommendation is not meant to imply that the additive could not be used safely (a) at different operating conditions, (b) in lower concentrations, or (c) on a part-time (on-demand) basis.

4. RESULTS AND DISCUSSION

The primary purpose of this investigation is to evaluate the effect of 0.1 volume per cent of methylcyclopentadienyl-manganese-tricarbonyl (Ethyl Corporation's smoke-suppressant additive designated CI-2) in a typical aviation-turbine fuel (containing 0.04 weight per cent sulfur) on surface-scale accumulations and hot-corrosion characteristics over a broad range of turbine-blade materials. The methods used to study the effect of the additive include visual and metallographic examinations of the test specimens along with analytical measurements of surface-scale accumulations (mg/cm^2), specimen weight-loss (mg/cm^2), surface-loss (mils) and maximum penetration of corrosion products (mils). The differential effects of CI-2 versus no CI-2 in the fuel resulting from the analytical measurements were separated from the experimental error associated with the measurements by statistical procedures.

In addition, since the data are available, comparisons are made, where possible, of the relative durability of the turbine-blade materials with respect to surface-scale accumulations and hot corrosion.

4.1. Specimen Exposure

A test program was designed (11) and tests were conducted under Navy Contract N00019-69-C-0221 to evaluate the effect of very low levels of sulfur in fuel on hot corrosion of turbine-blade materials when exposed in a marine environment. The tests were of 165 hours duration (33 periods of 5 hours each) with fuels containing 0.040 and 0.0004 weight per cent sulfur. The schedule of specimen exposure for each of the three rows of the specimen retainer is shown in Figures 66, 67, and 68 of Appendix 3, and a summary of the exposure of specimens at each time period is shown in Table 52 of Appendix 3. The test using 0.040 weight per cent sulfur in fuel was selected as the base line for the current investigation. Fuel from the same batch as used in the previous investigation (11) was blended with 0.1 volume per cent Ethyl CI-2 for use as the test fuel for the current investigation. Specimens from the same batches of superalloys and superalloy-coating systems used in the previous investigation (11) were used as test specimens for this investigation. The schedule of specimen exposure for the current investigation was modified for two of the three rows of the specimen retainer. The modified schedule of specimen exposure for each of the three rows of the specimen retainer is shown in Figures 69, 70, and 71 of Appendix 3 and a summary of specimen exposure at the various test hours is shown in Table 53 of Appendix 3.

In the previous investigation (11) specimens of the four least resistant superalloys (B-1900, Mar M-246, Mar M-200, and IN-100) were exposed in duplicate in each of the three rows of the specimen retainer to provide an estimate of the relative severity of the three rows of the specimen retainer. A difference in severity, based on weight-loss, among the three rows of the specimen retainer was found and comparisons of the relative durability of the superalloys and superalloy-coating systems were confined to a single row of the specimen retainer; however, comparisons of the effect of sulfur in fuel were not affected by the difference in severity among the rows. In the

current investigation specimens of B-1900, Mar M-246, Mar M-200 and IN-100 were exposed in only the third row of the specimen retainer which eliminated any evaluation of the relative severity of the three rows of the specimen retainer. With the elimination of a superalloy from a row of the specimen retainer the other superalloys were advanced for exposure while maintaining their position in the retainer. The elimination of these four superalloys from two of the three rows of the specimen retainer has no affect on comparisons of the effect of the manganese containing fuel additive (Ethyl CI-2) on surface scale and hot corrosion of the turbine-blade materials.

4.2. Visual Rating of Specimens

Visual ratings of the 48 specimens in the retainer were made after each five hours of exposure in the tests without and with CI-2 in the fuel using the rating scale shown in Table 50 of Appendix 3 (Section 10.4.). These ratings are shown in Figures 72 through 77 of Appendix 4 (Section 11.1).

A photograph showing the appearance of specimens after exposure, for 165 hours, without CI-2 in a fuel containing 0.0004 weight per cent sulfur is presented in Figure 1. The considerable variability in appearance of the specimens, and the lack of any appreciable amount of deposit, is clearly evident. Photographs showing the appearance of specimens after exposure for 5, 15, and 150 hours with 0.1 volume per cent CI-2 and 0.040 weight per cent sulfur in fuel are shown in Figures 2, 3, and 4. These photographs also show a considerable variability in appearance of the specimens and a rapid build-up of surface scale during the first 15 hours of the test with a tendency to level-off with additional exposure.

Specimens are free to rotate in the retainer during exposure and in making each rating the portion of the specimen facing upstream in the Turbine Simulator was rated; therefore, different portions of a specimen may have been rated from period to period. While the amount of surface scale on the specimens tended to build-up with time there was considerable flaking of deposits as the specimens were cooled to ambient temperature at the end of each 5-hour period. The rotation of the specimens and the flaking of deposits may have accounted for the discrepancy of some ratings of the specimens.

The visual ratings of the specimens have not been used in comparisons of the effect of CI-2 in fuel on hot corrosion of the turbine-blade materials or in the determination of the relative durability of the superalloys and superalloy-coating systems. However, a tabulation of visual ratings assigned at the time specimens were removed from test is presented in Table 14 in Section 4.5. to permit comparisons with weight-loss data.

4.3. Surface Scale

4.3.1. Weight of Surface Scale

Each specimen was weighed after it was removed from the specimen retainer following exposure. A sample of surface scale was removed by scraping with a stainless steel spatula and the specimen was then electro-cleaned. The difference between the weight of the specimen after exposure and after electro-cleaning was recorded as weight of surface scale. Scale was observed

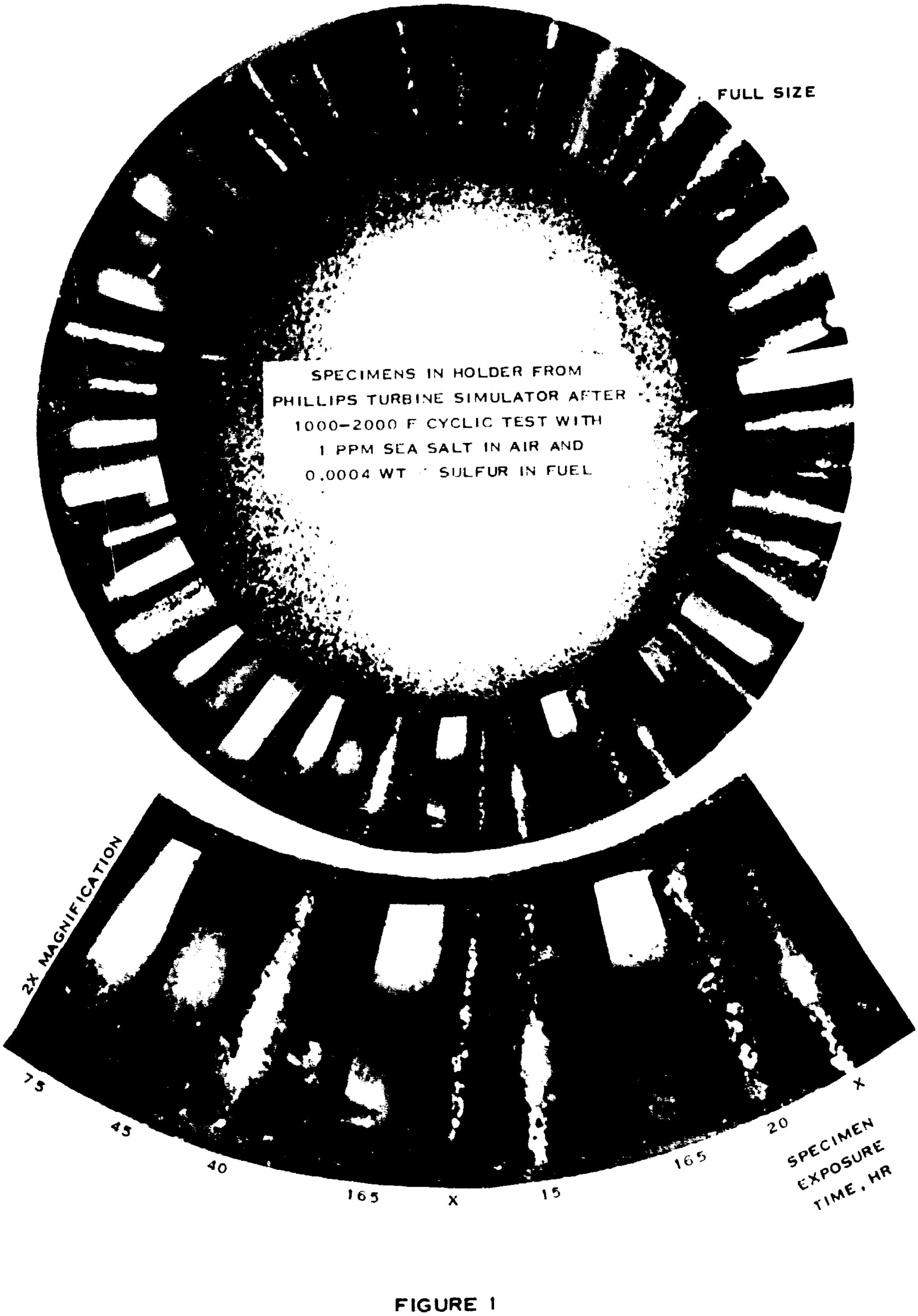


FIGURE 1
SLIGHT SURFACE SCALE ON TEST SPECIMENS AFTER 165 HOURS

FIGURE 2
SLIGHT DEPOSIT ON TEST SPECIMENS AFTER 5 HOURS WITH CI-2 IN FUEL

FIGURE 3
MODERATE DEPOSIT ON TEST SPECIMENS AFTER 15 HOURS WITH CI-2 IN FUEL

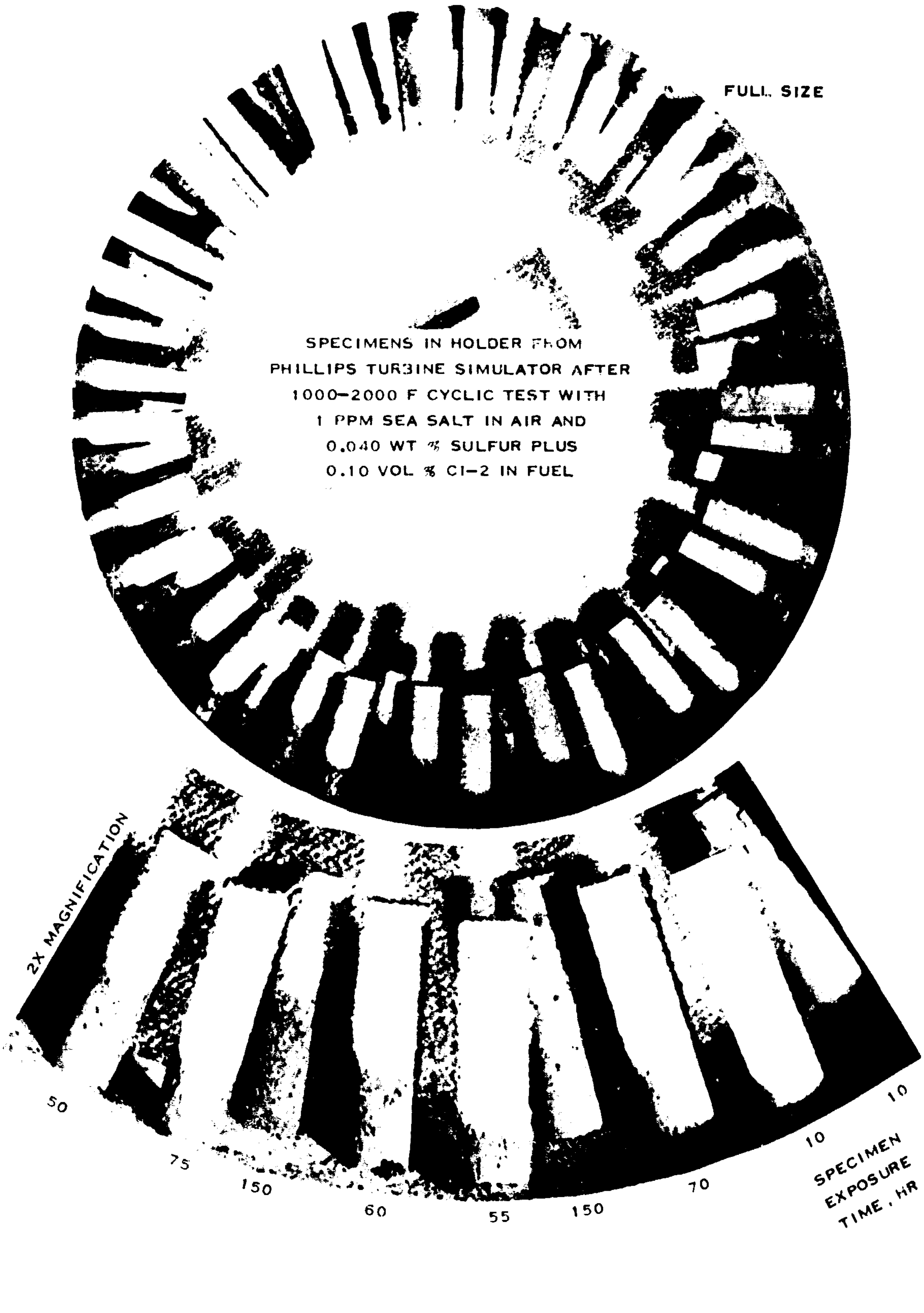


FIGURE 4
HEAVY DEPOSIT ON TEST SPECIMENS AFTER 150 HOURS WITH CI-2 IN FUEL

to flake off the specimens as they cooled to ambient temperature prior to weighing and the recorded weights may not represent the total amount of surface scale on a specimen while it is being exposed in the turbine simulator. The weight of surface scale and the weight of surface scale per unit area of new specimen for each specimen exposed with 0.040 weight per cent sulfur in the absence of CI-2 is presented in Table 54 of Appendix 4 (Section 11.2.) and the data for each specimen exposed with 0.040 weight per cent sulfur and 0.1 volume per cent CI-2 in fuel are shown in Table 55 of Appendix 4 (Section 11.2.). Specimens of four superalloys were exposed in each of the three rows of the specimen retainer in the base-line test without CI-2 and in only one row of the retainer in the fuel-additive test. A summary of the data for weight of surface scale for specimens exposed in the same position in each of the two tests is shown in Table 1.

The experimental investigation was designed to permit the use of statistical methods in evaluating the data obtained. In the analyses of data obtained (weight of surface scale, specimen weight-loss, surface-loss, and maximum penetration) an Analysis of Variance (AOV) technique has been used and a 95 per cent confidence level has been selected for determining statistically significant effects of the variables.

An explanation of some of the terms used in the statistical analyses of the data is given in the following paragraphs.

<u>Statistical Main Effects</u> -- In the absence of statistically significant interactions, the magnitude of significant main effects can be estimated from means of a variable averaged over all levels of the other variable or variables.

<u>Statistical Interactions</u> -- This is the failure of two or more variables to act independently of each other. This means that the magnitude of the effect of one variable is different at different levels of the other variable or variables. The effect of a variable is then estimated at each level of the variable or variables with which it interacts.

<u>Tolerable Spread between Means</u> (TSM) — If the difference between two means is equal to or greater than the TSM, the two means are said to be statistically different. A TSM is the spread expected to occur 95 per cent of the time between means which are from the same population where 95 per cent is the selected probability level. The TSM is estimated for comparisons of two means as follows: $TSM = t\sqrt{(1/N_1 + 1/N_2)(\sigma^2)}$ where the value for "t" is the appropriate tabular value for the selected probability level and the degrees of freedom associated with the error mean square, N_1 and N_2 are the number of observations in the two means being compared and σ^2 is the error mean square.

<u>Multiple Comparison Tests</u> -- This is a method of presenting several mean comparisons in tabular form. The distinction between this method and a listing of all mean differences is that the differences between individual means are not given, they are only indicated. The significance of differences are determined by use of the appropriate TSM's. The means to be compared are listed in ascending or descending order. If the difference between two means is not equal to or greater than the appropriate TSM a line is drawn under

TABLE 1

WEIGHT OF SURFACE SCALE ON TEST SPECIMENS

Superalloy	Coating	(a) Position	Exposure Time, hrs.	Weight of Surface Scale, mg/cm² No Additive(b)	0.1 % CI-2(c)
B-1900	None	3A	5	3.63	8.68
B-1900	None	3A	5	2.54	12.54
B-1900	None	3C	10	8.93	13.97
B-1900	None	3B	15	14.57	18.12
B-1900	None	3B	15	6.25	16.17
B-1900	None	3D	20	23.09	19.47
B-1900	MDC-1	2D	40	9.20	12.06
B-1900	MDC-1	2C	50	5.55	15.08
B-1900	MDC-1	2B	60	7.13	17.31
B-1900	MDC-1	2A	80	5.97	20.13
B-1900	MDC-9	2A	80	3.79	12.80
B-1900	MDC-9	2B	90	3.07	11.25
B-1900	MDC-9	2C	100	2.81	15.44
B-1900	MDC-9	2D	110	4.07	16.38
Mar M-246	None	3A	5	11.78	16.87
Mar M-246	None	3A	5	8.03	16.56
Mar M-246	None	3D	10	9.76	20.22
Mar M-246	None	3B	15	14.81	28.59
Mar M-246	None	3B	15	16.29	25.06
Mar M-246	None	3D	20	20.94	42.73
Mar M-246	MDC-1	2H	40	10.27	15.02
Mar M-246	MDC-1	2G	50	4.59	17.24
Mar M-246	MDC-1	2F	60	8.36	18.21
Mar M-246	MDC-1	2E	80	4.08	24.96
Mar M-246	MDC-9	2E	80	3.83	10.79
Mar M-246	MDC-9	2F	90	3.68	16.74
Mar M-246	MDC-9	2G	100	2.98	15.71
Mar M-246	MDC-9	2H	110	3.56	17.86
Mar M-200	None	3A	5	16.96	20.67
Mar M-200	None	3A	5	11.58	20.13
Mar M-200	None	3A	10	13.08	35.80
Mar M-200	None	3C	15	27.76	39.22
Mar M-200	None	3C	15	16.57	39.66
Mar M-200	None	3D	20	14.26	46.43

TABLE 1 (Cont'd)

Superalloy	Coating	(a) Position	Exposure Time, hrs	Weight of Surface Scale, mg/cm² No Additive(b)	0.1 % CI-2(c)
Mar M-200	MDC-1	2M	40	4.24	13.62
Mar M-200	MDC-1	2L	50	6.33	16.31
Mar M-200	MDC-1	2K	60	5.86	17.15
Mar M-200	MDC-1	2J	80	6.00	24.41
Mar M-200	MDC-9	2J	80	5.30	14.26
Mar M-200	MDC-9	2K	90	5.48	16.71
Mar M-200	MDC-9	2L	100	4.59	17.99
Mar M-200	MDC-9	2M	110	5.08	15.66
IN-100	None	3A	5	10.41	9.48
IN-100	None	3A	5	5.30	10.39
IN-100	None	3B	10	12.80	17.02
IN-100	None	3C	15	14.96	22.34
IN-100	None	3C	15	10.28	17.55
IN-100	None	3A	20	9.84	24.73
IN-100	MDC-1	2R	40	5.27	18.54
IN-100	MDC-1	2Q	50	4.63	13.60
IN-100	MDC-1	2P	60	5.09	9.88
IN-100	MDC-1	2N	80	6.02	12.32
IN-100	MDC-9	2N	45	2.45	16.51
IN-100	MDC-9	2P	55	6.20	20.75
IN-100	MDC-9	2Q	65	26.54	12.56
IN-100	MDC-9	2R	80	5.79	7.67
Inconel 713C	None	1K	10	10.06	15.30
Inconel 713C	None	1N	10	11.86	11.92
Inconel 713C	None	1K	20	9.66	14.33
Inconel 713C	None	1N	20	12.06	18.20
Inconel 713C	None	1L	30	10.45	21.02
Inconel 713C	None	1L	30	14.66	22.49
Inconel 713C	None	1M	40	9.72	23.63
Inconel 713C	None	1M	40	11.43	30.33
Inconel 713C	MDC-1	1E	35	2.95	13.90
Inconel 713C	MDC-1	1H	40	2.81	13.93
Inconel 713C	MDC-1	1F	50	4.55	11.34
Inconel 713C	MDC-1	1G	50	5.63	18.00
Inconel 713C	MDC-1	1G	65	6.53	16.78
Inconel 713C	MDC-1	1F	65	5.21	24.03
Inconel 713C	MDC-1	1H	80	5.35	15.30
Inconel 713C	MDC-1	1E	80	6.44	28.18

TABLE 1 (Cont'd)

Superalloy	Coating	(a) Position	Exposure Time, hrs	Weight of Surface Scale, mg/cm² No Additive(b)	0.1 % CI-2(c)
Inconel 713C	MDC-9	3J	165	6.16	27.34
Inconel 713C	MDC-9	3K	165	6.49	22.43
Udimet 700	None	1D	10	5.46	14.51
Udimet 700	None	1D	10	5.03	14.24
Udimet 700	None	1L	20	10.12	37.00
Udimet 700	None	1M	20	10.53	20.51
Udimet 700	None	1C	30	18.94	24.90
Udimet 700	None	1C	30	13.58	30.27
Udimet 700	None	1D	40	20.26	19.79
Udimet 700	None	1D	40	16.71	22.25
Udimet 700	MDC-1	1M	40	5.97	20.02
Udimet 700	MDC-1	1L	50	7.06	19.65
Udimet 700	MDC-1	1K	65	11.28	18.75
Udimet 700	MDC-1	1J	80	12.72	24.96
Udimet 700	MDC-9	3L	75	7.60	10.30
Udimet 700	MDC-9	3M	75	6.97	8.42
Udimet 700	MDC-9	3L	90	6.62	22.32
Udimet 700	MDC-9	3M	90	7.64	13.13
IN-738	None	1E	10	6.33	26.47
IN-738	None	1M	20	10.80	46.11
IN-738	None	1L	30	11.24	67.43
IN-738	None	1Q	40	12.11	65.36
IN-738	None	1J	60	18.47	111.90
IN-738	MDC-1	1F	40	3.42	16.00
IN-738	MDC-1	1D	50	4.99	13.53
IN-738	MDC-1	1C	65	10.70	17.06
IN-738	MDC-1	1B	80	14.86	16.25
IN-738	MDC-1	1A	95	4.87	20.19
IN-738	MDC-9	3N	165	7.40	25.90
IN-738	MDC-9	3P	165	8.09	48.88
Udimet 710	None	1E	10	5.46	13.83
Udimet 710	None	1J	20	8.66	21.52
Udimet 710	None	1H	30	11.82	32.38
Udimet 710	None	1Q	40	24.72	92.83
Udimet 710	None	1N	60	27.11	108.32
Udimet 710	None	1P	80	22.74	73.42

TABLE 1 (Cont'd)

Superalloy	Coating	(a) Position	Exposure Time, hrs	Weight of Surface Scale, mg/cm^2 No additive(b)	0.1 % CI-2(c)
Udimet 710	MDC-1	1G	40	4.28	14.56
Udimet 710	MDC-1	1N	50	6.61	20.28
Udimet 710	MDC-1	1P	65	19.42	27.43
Udimet 710	MDC-1	1Q	80	12.56	28.85
Udimet 710	MDC-1	1R	95	5.49	41.22
Udimet 710	MDC-9	3R	55	8.41	10.99
Udimet 710	MDC-9	3Q	75	5.60	10.94
Udimet 710	MDC-9	3Q	90	23.44	25.10
Udimet 710	MDC-9	3R	110	7.94	13.52
WI-52	None	2N	20	15.53	25.85
WI-52	None	3H	25	21.20	25.46
WI-52	None	3G	40	24.43	34.65
WI-52	None	3F	55	27.70	42.19
WI-52	None	3E	70	32.37	49.98
WI-52	MDC-9	1A	70	3.62	24.99
Mar M-509	None	3D	20	9.03	30.45
Mar M-509	None	3A	25	23.16	26.12
Mar M-509	None	3B	40	17.82	21.88
Mar M-509	None	3C	40	18.40	26.61
Mar M-509	None	3C	55	21.57	27.62
Mar m-509	None	3B	55	17.38	37.00
Mar M-509	None	3D	70	19.32	27.59
Mar M-509	None	3A	70	20.93	42.73
Mar M-509	MDC-9	1B	70	7.99	25.49
Mar M-302	None	2P	20	13.04	32.55
Mar M-302	None	3H	25	17.98	36.02
Mar M-302	None	3G	40	22.10	40.62
Mar M-302	None	3F	55	26.91	44.96
Mar M-302	None	3E	70	20.66	52.36
Mar M-302	MDC-9	1K	70	12.18	24.11

TABLE 1 (Cont'd)

Superalloy	Coating	(a) Position	Exposure Time, hrs	Weight of Surface Scale, mg/cm^2 No additive(b)	0.1 % CI-2(c)
X-40	None	2P	20	12.76	22.36
X-40	None	3E	25	12.40	19.68
X-40	None	3F	55	16.89	29.63
X-40	None	3G	85	24.69	49.40
X-40	None	3H	115	44.00	92.92
X-40	MDC-9	1R	70	2.98	24.57
AiResist 215	None	2F	15	5.14	15.30
AiResist 215	None	2R	40	15.76	25.78
AiResist 215	None	2Q	45	18.59	28.45

Notes:

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row. Letter = Position in Row.

(b) 1 ppm sea salt in air.
0.040 weight per cent sulfur in fuel.

(c) 1 ppm sea salt in air.
0.040 weight per cent sulfur and 0.10 volume per cent Ethyl CI-2 in fuel.

both means and they are declared to be not statistically different. If the difference between two means is equal to or greater than the appropriate TSM a separate line is drawn under each of the two means and they are declared to be statistically different.

In this experiment the superalloys and superalloy-coating systems were grouped as to location in rows of the specimen retainer and hours of exposure and the analyses will be conducted on the basis of the grouping of the specimens. The bare superalloys were divided into the following three groups: B-1900, Mar M-246, Mar M-200, and IN-100, which are low-chromium, nickel-base materials were exposed for four different lengths of time in Row 3 of the specimen retainer; Udimet 700, Udimet 710, IN-738, and Inconel 713C, which are high-chromium, nickel-base materials, were exposed for four time periods in Row 1 of the specimen retainer; and specimens of WI-52, Mar M-509, Mar M-302, and X-40, which are cobalt-base materials, were exposed for various lengths of time in Row 3 of the specimen retainer. Specimens of MDC-1 coated nickel-base superalloys were divided into the following two groups: Misco MDC-1 coated B-1900, Mar M-246, Mar M-200, and IN-100 were exposed for various periods of time in Row 2 of the specimen retainer; and specimens of Misco MDC-1 coated Udimet 700, Udimet 710, IN-738, and Inconel 713C were exposed in Row 1 of the specimen retainer for multiple periods of time. Specimens of the twelve superalloys with Misco MDC-9 coating were divided into the following groups: MDC-9 coated B-1900, Mar M-246, Mar M-200, and IN-100 were exposed for various periods of time in Row 2 of the specimen retainer; MDC-9 coated Udimet 700 and 710 specimens were exposed for 75 and 90 hours in Row 3 of the specimen retainer and Udimet 710 was also exposed for 55 and 110 hours; MDC-9 coated Inconel 713C and IN-738 were exposed in duplicate for 165 hours in Row 3 of the specimen retainer: and single specimens of MDC-9 coated WI-52, Mar M-509, Mar M-302, and X-40 were exposed for 70 hours in Row 1 of the specimen retainer.

An Analysis of Variance (AOV) was made for each group using the data for the method of evaluation being used (weight of surface scale, weight-loss, etc.) and means of the data were examined for significant effects on the basis of the comparisons indicated by the AOV. For the sake of brevity; however, most of the summary tables of the AOV's are not shown in this report.

An example of an Analysis of Variance is shown in Table 2 for data on weight of surface scale on bare specimens of B-1900, Mar M-246, Mar M-200, and IN-100. In this AOV statistically significant interactions are indicated for superalloys by fuel-additive and time-of-exposure by fuel-additive. With these interactions, comparisons of the effect of the fuel additive on weight of surface scale should be made with superalloys and hours-of-exposure fixed. Means of comparisons for these four superalloys are shown in Table 3. The addition of 0.1 volume per cent CI-2 to the fuel had no statistically significant effect on the weight of surface scale on specimens of B-1900 exposed for any of the four time periods. With the other three superalloys, the addition of CI-2 to the fuel significantly increased the weight of surface scale on specimens exposed for 20 hours. In all cases where the addition of CI-2 to the fuel significantly affected weight of surface scale the effect was to increase the amount of scale.

TABLE 2

ANALYSIS OF VARIANCE OF WEIGHT OF SURFACE SCALE FOR BARE SUPERALLOYS
(B-1900, Mar M-246, Mar M-200, and IN-100)

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	47	4656.2986	
Metal (M)	3	1233.8313	411.2771
Time (T)	3	1183.5272	394.5091
Additive (A)	1	1179.8850	1179.8850
M x T	9	190.8969	21.2108
M x A	3	266.5298	88.8433 *
T x A	3	158.2146	52.7382 *
M x T x A	9	270.7879	30.0875
Error (Pooled)	85	1283.5987	15.1011

Asterisk (*) indicates a significant effect at 95 per cent confidence level.

TABLE 3

EFFECT OF CI-2 ON WEIGHT OF SURFACE SCALE ON BARE SUPERALLOYS
(B-1900, Mar M-246, Mar M-200, and IN-100)

Superalloy	CI-2 in Fuel	Mean Weight of Surface Scale, mg/cm², at Test Hours 5	10	15	20
B-1900	A_0	3.08	8.93	10.41	23.09
	A_1	10.61	13.97	17.14	19.49
MM-246	A_0	9.90	9.78	15.55	20.94
	A_1	16.72	20.22	26.82	42.73
MM-200	A_0	14.27	13.08	22.16	14.26
	A_1	20.40	35.80	39.44	46.43
IN-100	A_0	7.86	12.80	12.62	9.84
	A_1	9.94	17.02	19.94	24.73

Superalloy	Difference $A_1 - A_0$, mg/cm², at Test Hours 5 (a)	10 (b)	15 (a)	20 (b)
B-1900	7.53	5.04	6.73	-3.60
MM-246	6.82	10.44	11.27 *	21.79 *
MM-200	6.13	22.72 *	17.28 *	32.17 *
IN-100	2.08	4.22	7.32	14.89 *

A_0 = Test fuel without CI-2 additive.

A_1 = Test fuel with 0.1 volume per cent CI-2 additive.

(a) TSM = 7.77
(b) TSM = 10.99

Asterisk (*) indicates a significant difference at 95 per cent confidence level.

The AOV of the weight of surface scale data for Udimet 700, Udimet 710, IN-738, and Inconel 713C indicated a significant superalloy by time-of-exposure by fuel-additive; thus, means and comparisons of the data (Table 4) are made with superalloys and time-of-exposure fixed. For each superalloy the addition of CI-2 to the fuel had a significant effect on weight of surface scale at two or more times of exposure and in each case where there was a significant effect of CI-2, the effect was to increase the weight of surface scale on the specimens.

Two AOV's of the data on weight of surface scale were made to provide comparisons with the various times of exposure and the means and comparisons indicated by the AOV's are shown in Table 5. For specimens of WI-52, Mar M-509, and Mar M-302 exposed at 25, 40, 55, and 70 hours a significant effect of the addition of 0.1 volume per cent CI-2 in fuel is shown for specimens of Mar M-302 exposed for each of the time periods and for WI-52 and Mar M-509 exposed at 55 and 70 hours. The effect of CI-2 in fuel on the weight of surface scale for the four superalloys exposed for 25 and 55 hours was significant for each comparison.

For the bare superalloys, in all cases where a significant effect of CI-2 in the fuel was shown the additive increased weight of surface scale.

The analyses of duplicate observations indicated that for measurement of weight of surface scale the experimental error was different for the additive and non-additive treated fuels when specimens of coated superalloys were exposed. AOV's for the data on weight of surface scale on specimens of MDC-1 and MDC-9 coated specimens were made and the error estimate for additive treated fuel was $\hat{\sigma}_1^2 = 63.1977$ and the error estimate for the non-additive fuel was $\hat{\sigma}_0^2 = 0.9330$. This wide difference in error estimates negates pooling to check for interactions among coated metals.

For each metal the exposure time induces build-up and flaking-off of surface scale with a residue on the specimen at any time. The method used to estimate the effect of the fuel additive on the coated superalloys is as follows. The additive effect has been estimated for each alloy averaged over exposure time. A test statistic, t', is calculated in the following manner.

$$t' = \frac{A_1 - A_0}{\sqrt{\frac{\hat{\sigma}_1^2}{N_1} + \frac{\hat{\sigma}_0^2}{N_0}}}$$

Where: A_0 = Mean weight of surface scale without additive,
A_1 = Mean weight of surface with 0.1 per cent CI-2,

$\hat{\sigma}_0^2$ = Error estimate for test without CI-2,

$\hat{\sigma}_1^2$ = Error estimate for test with CI-2, and

N_0, N_1 = Number of specimens exposed at each condition.

This statistic is compared to the Students t with (N-1) degrees of freedom rather than 2(N-1) degrees of freedom. This is a more conservative test than

TABLE 4

EFFECT OF CI-2 ON WEIGHT OF SURFACE SCALE ON BARE SUPERALLOYS
(Udimet 700, Udimet 710, IN-738, and Inconel 713C)

Superalloy	CI-2 in Fuel	Mean Weight of Surface Scale, mg/cm^2, at Test Hours 10	20	30	40
Inco 713C	A_0	10.96	10.86	12.56	10.58
	A_1	13.61	16.26	21.76	26.98
Udimet 700	A_0	5.24	10.32	16.26	18.48
	A_1	14.38	28.76	27.58	21.02
IN-738	A_0	6.33	10.80	11.24	12.11
	A_1	26.47	46.11	67.73	65.36
Udimet 710	A_0	5.46	8.66	11.82	24.72
	A_1	13.83	21.52	32.38	92.83

Superalloy	Difference $A_1 - A_0$, mg/cm^2, at Test Hours 10	20	30	40
Inco 713C (a)	2.65	5.40	9.20 *	16.40 *
Udimet 700 (a)	9.14 *	18.44 *	11.32 *	2.54
IN-738 (b)	20.14 *	35.31 *	56.49 *	53.25 *
Udimet 710 (b)	8.37	12.86 *	20.56 *	68.11 *

A_0 = Test fuel without CI-2 additive.

A_1 = Test fuel with 0.1 volume per cent CI-2 additive.

(a) TSM = 7.77
(b) TSM - 10.99

Asterisk (*) indicates a significant difference at 95 per cent confidence level.

TABLE 5

EFFECT OF CI-2 ON WEIGHT OF SURFACE SCALE ON BARE SUPERALLOYS

At 25, 40, 55, and 70 hours -- WI-52, Mar M-509, and Mar M-302

Superalloy	CI-2 in Fuel	Mean Weight of Surface Scale, mg/cm², at Test Hours 25	40	55	70
WI-52	A_0	21.20	24.43	27.70	32.37
	A_1	25.46	34.65	42.19	49.98
MM-509	A_0	23.16	18.11	19.48	20.12
	A_1	26.12	24.24	32.31	35.16
MM-302	A_0	17.98	22.10	26.91	20.66
	A_1	36.02	40.62	44.96	52.36

Superalloy	Difference $A_1 - A_0$, mg/cm², at Test Hours 25	40	55	70
WI-52	(a) 4.26	(a) 10.22	(a) 14.49 *	(a) 17.61 *
MM-509	(a) 2.96	(b) 6.13	(b) 12.83 *	(b) 15.04 *
MM-302	(a) 18.04 *	(a) 18.52 *	(a) 18.05 *	(a) 31.70 *

At 25 and 55 hours -- WI-52, Mar M-509, Mar M-302, and X-40

	CI-2 in Fuel	Mean Weight of Surface Scale, mg/cm² WI-52	MM-509	MM-302	X-40
	A_0	24.45	19.80	22.44	14.64
	A_1	33.82	29.94	40.49	24.66
Difference	$A_1 - A_0$	(c) 9.37 *	(d) 10.14 *	(c) 13.05 *	(c) 10.02 *

A_0 = Test fuel without CI-2 additive.

A_1 = Test fuel with 0.1 volume per cent CI-2 additive.

(a) TSM = 10.99
(b) TSM = 7.77
(c) TSM = 5.49
(d) TSM = 4.15

Asterisk (*) indicates a significant difference at 95 per cent confidence level.

the ordinary t-test.

The means of weight of surface scale on coated superalloys, with and without CI-2 in the fuel, and tests for significance of the effect of CI-2 in the fuel on weight of surface scale are shown in Table 6. The weight of surface scale was increased significantly on seven of the eight MDC-1 coated superalloys and seven of the twelve MDC-9 coated superalloys when 0.1 volume per cent CI-2 was added to the fuel. CI-2 in the fuel had no statistical effect on weight of surface scale on either MDC-1 or MDC-9 coated IN-100. The weight of surface scale was not significantly effected by CI-2 on MDC-9 coated Udimet 700, Udimet 710, Mar M-509, or Mar M-302.

In all cases where a significant effect of 0.1 volume per cent CI-2 in fuel was found on either the superalloys or superalloy-coating systems the effect of the CI-2 was to increase the weight of surface scale on the specimens. The larger amount of surface scale on specimens exposed in the presence of CI-2 in fuel is also shown in Figure 5.

Comparisons of the relative amount of surface scale observed on the various superalloys and superalloy-coating systems are of interest to determine the relative contributions of the metals to the weight of surface scale. Comparisons of the mean weight of surface scale on bare superalloys have been made in Table 7 with the appropriate variables fixed on the basis of the effects and interactions found in the AOV's of the data.

In the absence of 0.1 volume per cent CI-2 in fuel, the weight of surface scale on B-1900 specimens is less than on Mar M-246 or Mar M-200; however, the difference between B-1900 and IN-100, IN-100 and Mar M-246, or Mar M-246 and Mar M-200 is not significant. In the presence of 0.1 volume per cent CI-2 in fuel the weight of surface scale on B-1900 and IN-100 specimens is significantly less than on specimens of Mar M-246 and Mar M-200.

Comparisons of weight of surface scale on specimens of bare Udimet 710, Udimet 700, IN-738, and Inconel 713C are made with both time-of-exposure and additive-in-fuel fixed. In the absence of CI-2 in fuel the only statistically significant differences in weight of surface scale are with 40 hours of exposure, where weight of surface scale on Inconel 713C specimens is less than on Udimet 700 or Udimet 710, and weight of surface scale on IN-738 is less than on Udimet 710 specimens. In the presence of 0.1 volume per cent CI-2 in fuel, exposed specimens of Inconel 713C were in the group with the least weight of surface scale at each of the four test periods. At 10, 20, and 30 hours, specimens of IN-738 had the greatest amount of surface scale. With 40 hours of exposure, weight of surface scale on specimens of Udimet 710 was the greatest with the weight of surface scale on IN-738 being the next largest.

In the absence of CI-2 in the fuel the only statistically significant difference in the comparisons of Mar M-509, Mar M-302, and WI-52 was with 70 hours of exposure where the weight of surface scale on specimens of WI-52 was greater than on the other two superalloys. In comparisons of the four superalloys, the surface scale on specimens of X-40 was less than on specimens of Mar M-509, Mar M-302, and WI-52. In comparisons of weight of surface scale on specimens of Mar M-509, Mar M-302, and WI-52 exposed in the

TABLE 6

EFFECT OF CI-2 ON WEIGHT OF SURFACE SCALE ON COATED SUPERALLOYS

$$t' = \frac{A_1 - A_0}{\sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_0^2}{N_0}}}$$

Superalloy	MDC-1 Coating	MDC-9 Coating
B-1900	$t' = \frac{16.14 - 6.96}{\sqrt{64.1306/4}} = 2.30$ *	$t' = \frac{13.97 - 3.44}{\sqrt{64.1306/4}} = 2.63$ *
Mar M-246	$t' = \frac{18.86 - 6.82}{\sqrt{64.1306/4}} = 3.01$ *	$t' = \frac{15.28 - 3.51}{\sqrt{64.1306/4}} = 2.94$ *
Mar M-200	$t' = \frac{17.87 - 5.61}{\sqrt{64.1306/4}} = 3.06$ *	$t' = \frac{16.16 - 5.11}{\sqrt{64.1306/4}} = 2.76$ *
IN-100	$t' = \frac{13.58 - 5.25}{\sqrt{64.1306/4}} = 2.08$	$t' = \frac{14.37 - 10.24}{\sqrt{64.1306/4}} = 1.03$
Inconel 713C	$t' = \frac{17.68 - 4.93}{\sqrt{64.1306/8}} = 4.50$ *	$t' = \frac{24.88 - 6.32}{\sqrt{64.1306/2}} = 3.28$ *
Udimet 700	$t' = \frac{20.84 - 9.26}{\sqrt{64.1306/4}} = 2.90$ *	$t' = \frac{13.54 - 7.21}{\sqrt{64.1306/4}} = 1.58$
IN-738	$t' = \frac{16.61 - 7.77}{\sqrt{64.1306/5}} = 2.47$ *	$t' = \frac{37.39 - 7.74}{\sqrt{64.1306/2}} = 5.24$ *
Udimet 710	$t' = \frac{26.47 - 9.67}{\sqrt{64.1306/5}} = 4.69$ *	$t' = \frac{15.14 - 11.35}{\sqrt{64.1306/4}} = 0.95$
WI-52	Not Tested	$t' = \frac{24.99 - 3.62}{\sqrt{64.1306/1}} = 2.67$ *
Mar M-509	Not Tested	$t' = \frac{25.49 - 7.99}{\sqrt{64.1306/1}} = 2.19$
Mar M-302	Not Tested	$t' = \frac{24.11 - 12.18}{\sqrt{64.1306/1}} = 1.49$
X-40	Not Tested	$t' = \frac{24.57 - 2.96}{\sqrt{64.1306/1}} = 2.70$ *

Notes: Student t with 10 degrees of freedom = 2.23
Asterisk (*) indicates a significant difference at 95 per cent level.

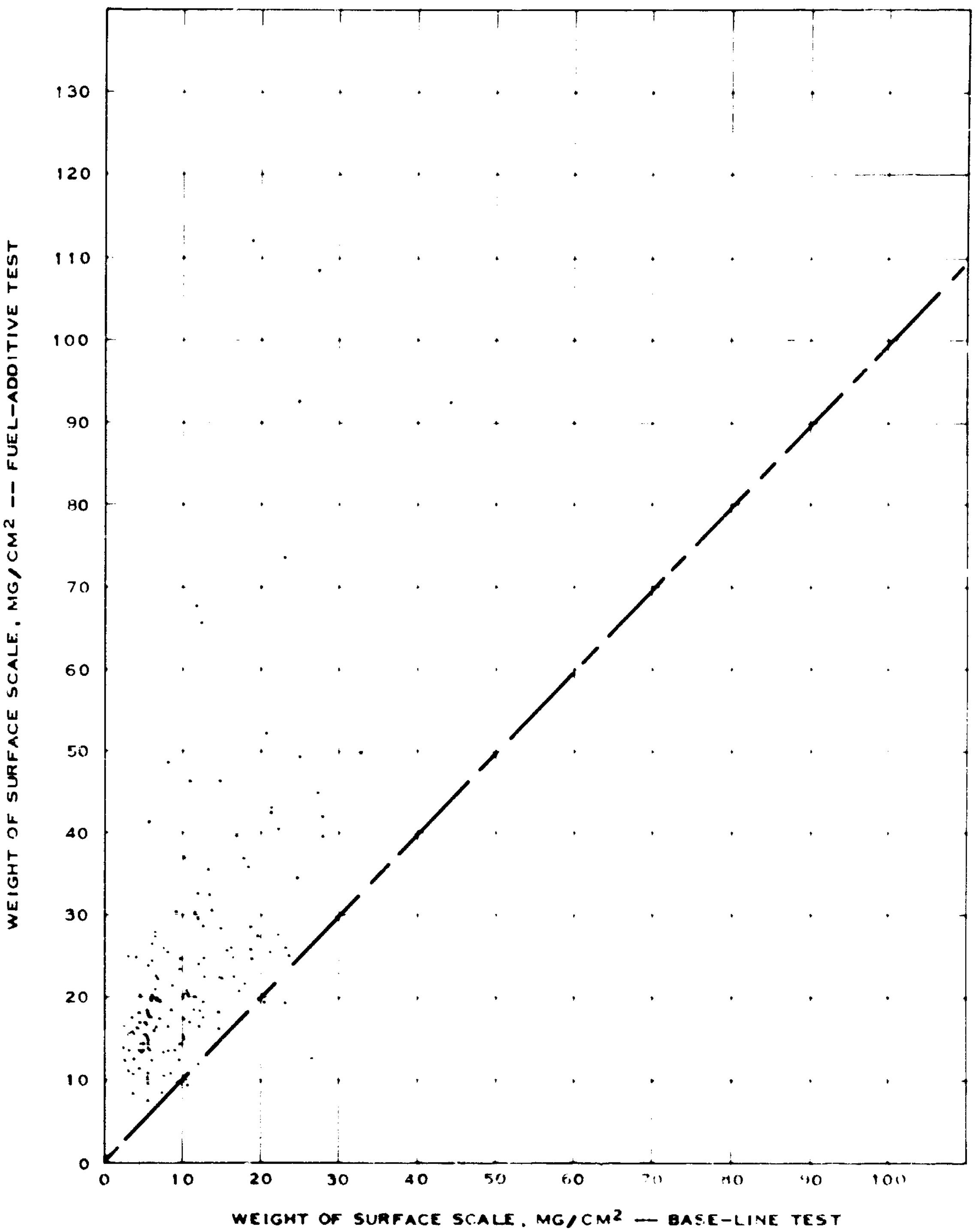


FIGURE 5
EFFECT OF CI-2 IN FUEL ON WEIGHT OF SURFACE SCALE

TABLE 7

COMPARISON OF WEIGHT OF SURFACE SCALE ON BARE SUPERALLOYS

Mean Weight of Surface Scale, mg/cm²							
Without CI-2 in Fuel				With 0.1 % CI-2 in Fuel			
(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)
B-1900	IN-100	MM-246	MM-200	B-1900	IN-100	MM-246	MM-200
9.84	10.60	13.60	16.70	14.83	16.92	25.00	33.65
			10 hours				
(2)	(1)	(1)	(2)	(2)	(1)	(2)	(1)
U-700	U-710	IN-738	I-713C	I-713C	U-710	U-700	IN-738
5.24	5.46	6.33	10.96	13.61	13.83	14.38	26.47
			20 hours				
(1)	(2)	(1)	(2)	(2)	(1)	(2)	(1)
U-710	U-700	IN-738	I-713C	I-713C	U-710	U-700	IN-738
8.66	10.32	10.80	10.86	16.26	21.52	28.76	46.11
			30 hours				
(1)	(1)	(2)	(2)	(2)	(2)	(1)	(1)
IN-738	U-710	I-713C	U-700	I-713C	U-700	U-710	IN-738
11.24	11.82	12.56	16.26	21.76	27.58	32.38	67.73
			40 hours				
(2)	(1)	(2)	(1)	(2)	(2)	(1)	(1)
I-713C	IN-738	U-700	U-710	U-700	I-713C	IN-738	U-710
10.58	12.11	18.48	24.72	21.02	26.98	65.36	92.93
			25 hours				
(1)	(1)	(1)		(1)	(1)	(1)	
MM-302	WI-52	MM-509		WI-52	MM-509	MM-302	
17.9[illegible]	21.20	23.16		25.46	26.12	36.02	
			40 hours				
(2)	(1)	(1)		(2)	(1)	(1)	
MM-509	MM-302	WI-52		MM-509	WI-52	MM-302	
18.11	22.10	24.43		24.24	34.65	40.62	

Notes: Values in parentheses ( ) indicate number of observations.

TSM = 4.49 (6 vs 6) TSM = 7.77 (2 vs 2)
TSM = 4.87 (4 vs 7) TSM = 9.52 (2 vs 1)
TSM = 5.49 (4 vs 4) TSM = 10.99 (1 vs 1)

TABLE 7 (Cont'd)

Mean Weight of Surface Scale, mg/cm²

Without CI-2 in Fuel				With 0.1 % CI-2 in Fuel			
55 hours							
(2) MM-509	(1) MM-302	(1) WI-52		(2) MM-509	(1) WI-52	(1) MM-302	
19.48	26.91	27.70		32.31	42.19	44.96	
70 hours							
(2) MM-509	(1) MM-302	(1) WI-52		(2) MM-509	(1) WI-52	(1) MM-302	
20.12	20.66	32.47		35.16	49.98	52.36	
25 and 55 hours							
(4) X-40	(7) MM-509	(4) MM-302	(4) WI-52	(4) X-40	(7) MM-509	(4) WI-52	(4) MM-302
14.64	19.80	22.44	24.45	24.66	29.94	33.82	40.49

Notes:

Values in parentheses ( ) indicate number of observations.

TSM = 4.49 (6 vs 6)
TSM = 4.87 (4 vs 7)
TSM = 5.49 (4 vs 4)
TSM = 7.77 (2 vs 2)
TSM = 9.52 (2 vs 1)
TSM = 10.99 (1 vs 1)

presence of 0.1 volume per cent CI-2 in fuel, where statistically significant differences were shown, the surface scale on specimens of Mar M-302 was greater than on WI-52 or Mar M-509. The weight of surface scale on specimens of WI-52 and Mar M-509 varied with time-of-exposure, with weight of surface scale being greater, less, and equal to the weight of surface scale on specimens of Mar M-509. In comparisons of the weight of surface scale on the four superalloys exposed in the presence of CI-2 in fuel, the weight of surface scale was significantly less on specimens of X-40 than on specimens of the other three superalloys, the weight of surface scale on specimens of Mar M-302 was significantly greater than on the other three superalloys, and there was no significant difference in weight of surface scale on specimens of WI-52 and Mar M-509.

Comparisons of the weight of surface scale on specimens of MDC-1 coated superalloys exposed without and with 0.1 volume per cent CI-2 in fuel are shown in Table 8. In the absence of CI-2 in fuel the weight of surface scale on MDC-1 coated specimens of Mar M-200, IN-100, B-1900 and Mar M-246 was light. The weight of surface scale on specimens of MDC-1 coated Mar M-200 and IN-100 was significantly less than on MDC-1 coated B-1900 and Mar M-246 specimens exposed for 40 hours, the weight of surface scale on specimens of MDC-1 coated IN-100 was significantly less than on specimens of MDC-1 coated Mar M-246 exposed for 60 hours and there were no other statistically significant differences in weight of surface scale on these four superalloy-coating systems. There were no statistically significant differences in weight of surface scale found on these four superalloy-coating systems in the presence of 0.1 volume per cent CI-2 in fuel.

Comparisons of the weight of surface scale on specimens of MDC-1 coated Inconel 713C, IN-738, Udimet 700, and Udimet 710 exposed in the absence of CI-2 in fuel showed that the weight of surface scale on MDC-1 coated Inconel 713C specimens was significantly less than on specimens of MDC-1 coated Udimet 700 exposed for 40 hours and significantly less than for the other three superalloy-coating systems exposed for 65 or 80 hours. The weight of surface scale on specimens of MDC-1 coated Udimet 710 exposed for 65 hours was greater than for the other three superalloy-coating systems exposed for the same period of time. There was no significant difference in weight of surface scale on these four superalloy-coating systems exposed for 50 hours in the absence of CI-2 in fuel or with 0.1 volume per cent CI-2 in fuel after 40, 50, 65, or 80 hours of exposure.

Comparisons of the weight of surface scale on specimens of MDC-9 coated superalloys exposed without and with 0.1 volume per cent CI-2 in fuel are shown in Table 9. In the absence of CI-2 in fuel the weight of surface scale on MDC-9 coated Mar M-200 specimens was heavier than on MDC-9 coated specimens of B-1900 or Mar M-246. In the presence of 0.1 volume per cent CI-2 in fuel there was no statistically significant difference in weight of surface scale on the three superalloy-coating systems. The only statistically significant difference between MDC-9 coated Udimet 700 and Udimet 710 is shown for specimens exposed for 90 hours in the absence of CI-2 in fuel. No statistically significant difference in weight of surface scale was shown for MDC-9 coated specimens of Inconel 713C and IN-738 exposed for 165 hours with or without CI-2 in fuel. Weight of surface scale was greater on specimens of MDC-9 coated Mar M-509 and Mar M-302 than on specimens of MDC-9 coated X-40

TABLE 8

COMPARISON OF WEIGHT OF SURFACE SCALE ON MDC-1 COATED SUPERALLOYS

Mean Weight of Surface Scale, mg/cm^2							
Without CI-2 in Fuel				With 0.1 % CI-2 in Fuel			
40 hours							
(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
MM-200	IN-100	B-1900	MM-246	B-1900	MM-200	MM-246	IN-100
4.24	5.27	9.20	10.27	12.06	12.62	15.02	18.54
50 hours							
(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
MM-246	IN-100	B-1900	MM-200	IN-100	B-1900	MM-200	MM-246
4.59	4.63	5.55	6.38	13.60	15.08	16.31	17.24
60 hours							
(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
IN-100	MM-200	B-1900	MM-246	IN-100	MM-200	B-1900	MM-246
5.09	5.86	7.13	8.36	9.88	17.15	17.31	18.21
80 hours							
(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
MM-246	B-1900	MM-200	IN-100	IN-100	B-1900	MM-200	MM-246
4.08	5.97	6.00	6.02	12.32	20.13	24.41	24.96
40 hours							
(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
I-713C	IN-738	U-710	U-700	I-713C	U-710	IN-738	U-700
2.81	3.42	4.28	5.97	13.93	14.56	16.00	20.02
50 hours							
(1)	(2)	(1)	(1)	(1)	(2)	(1)	(1)
IN-738	I-713C	U-710	U-700	IN-738	I-713C	U-700	U-710
4.99	5.09	6.61	7.06	13.53	14.67	19.65	20.28

Notes:

Values in parentheses ( ) indicate number of observations.

Without CI-2 in Fuel	With 0.1 % CI-2 in Fuel
TSM = 2.73 (1 vs 1)	TSM = 22.48 (1 vs 1)
TSM = 2.36 (2 vs 1)	TSM = 19.47 (2 vs 1)

TABLE 8 (Cont'd)

Mean Weight of Surface Scale, mg/cm^2

Without CI-2 in Fuel | With 0.1 % CI-2 in Fuel

65 hours

(2) I-713C	(1) IN-738	(1) U-700	(1) U-710	(1) IN-738	(1) U-700	(2) I-713C	(1) U-710
5.87	10.70	11.28	19.42	17.06	18.75	20.40	27.43

80 hours

(2) I-713C	(1) U-710	(1) U-700	(1) IN-738	(1) IN-738	(1) I-713C	(2) U-700	(1) U-710
6.40	12.56	12.72	14.86	16.25	21.74	24.96	28.85

Notes:

Values in parentheses ( ) indicate number of observations.

Without CI-2 in Fuel	With 0.1 % CI-2 in Fuel
TSM = 2.73 (1 vs 1)	TSM = 22.48 (1 vs 1)
TSM = 2.36 (2 vs 1)	TSM = 19.47 (2 vs 1)

TABLE 9

COMPARISON OF WEIGHT OF SURFACE SCALE ON MDC-9 COATED SUPERALLOYS

Mean Weight of Surface Scale, mg/cm^2							
Without CI-2 in Fuel				With 0.1 % CI-2 in Fuel			
80, 90, 100, and 110 hours							
(4)	(4)	(4)		(4)	(4)	(4)	
B-1900	MM-246	MM-200		B-1900	MM-246	MM-200	
3.44	3.51	5.11		13.97	15.28	16.16	
75 hours		90 hours		75 hours		90 hours	
(1)	(2)	(2)	(1)	(2)	(1)	(2)	(1)
U-710	U-700	U-700	U-710	U-700	U-710	U-700	U-710
5.60	7.28	7.18	23.44	9.36	10.94	17.72	25.10
165 hours							
(2)	(2)			(2)	(2)		
I-713C	IN-738			I-713C	IN-738		
6.32	7.74			24.88	37.39		
70 hours							
(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
X-40	WI-52	MM-509	MM-302	MM-302	X-40	WI-52	MM-509
2.98	3.62	7.99	12.18	24.11	24.57	24.99	25.49

Notes:

Values in parentheses ( ) indicate number of observations.

Without CI-2 in Fuel	With 0.1 % CI-2 in Fuel
TSM = 2.73 (1 vs 1)	TSM = 22.48 (1 vs 1)
TSM = 2.36 (2 vs 1)	TSM = 19.47 (2 vs 1)
TSM = 1.93 (2 vs 2)	TSM = 15.90 (2 vs 2)
TSM = 1.36 (4 vs 4)	TSM = 11.24 (4 vs 4)

and WI-52 when exposed for 70 hours in the absence of CI-2 in fuel. In the presence of 0.1 volume per cent CI-2 in fuel there was no significant difference in the weight of surface scale on the four superalloy-coating systems.

Comparisons of the weight of surface scale on bare vs MDC-1 coated specimens of Inconel 713C, IN-738, Udimet 700, and Udimet 710 are shown in Table 10. This table shows that weight of surface scale on the MDC-1 coated superalloy was significantly less than the weight of surface scale on the corresponding bare superalloy when exposed in the absence of CI-2 in the fuel. For specimens exposed in the presence of 0.1 volume per cent CI-2 in fuel the weight of surface scale on bare Udimet 710 was greater than the weight of surface scale on bare IN-738 and the weight of surface scale on bare IN-738 was greater than on the remaining bare superalloys or superalloy-coating systems.

The differences in weight of surface scale on MDC-9 coated superalloys and between bare and MDC-1 coated superalloys are reduced by the presence of 0.1 volume per cent CI-2 in the fuel.

Comparisons of the weight of surface scale on MDC-1 and MDC-9 coated specimens of B-1900, Mar M-246, Mar M-200 and IN-100 are shown in Table 11. There is no statistically significant difference in weight of surface scale indicated for the specimens exposed with or without CI-2 in the fuel.

In general, these statistical analyses shows that the use of 0.1 volume per cent CI-2 in JP-5 fuel will tend to increase surface-scale accumulations above the amount that would be obtained for the same period of exposure with a fuel not containing the additive—regardless of the turbine-blade material employed. The magnitude of this increase may be somewhat dependent on exposure time and turbine-blade material; however, from a practical standpoint these subtle differences may only be academic. For example, it can be shown that 22 of the 32 turbine-blade materials at one or more periods of exposure resulted in increases of greater than 100 per cent in surface-scale accumulations as a result of CI-2 in the fuel when comparisons of appropriate means are made, and the ten turbine-blade materials that showed increases of less than 100 per cent, essentially all tended to approach this high-level increase. Since it has been observed that the deposits tend to flake-off during exposure, it is possible that the lower percentage increases in weight simply reflect this reduced weight resulting from flake-off rather than represent a real effect of alloys. In addition, this flake-off problem would tend to obscure the effects of exposure-time. Thus, the indication from this study is that the use of CI-2 on a continuous basis can cause serious surface-scale accumulations regardless of the turbine-blade material that might be employed. This means that a definite risk would be taken with respect to aircraft performance if this additive is used continuously under realistic aircraft-turbine operating conditions at concentrations in JP-5 fuel of 0.1 volume per cent. However, this conclusion is not to be construed to imply that the additive could not be safely used (a) at different operating conditions, (b) in lower concentrations, or (c) on a part-time (on-demand) basis.

TABLE 10

COMPARISON OF WEIGHT OF SURFACE SCALE ON BARE VS MDC-1 COATED SUPERALLOYS
(Row 1 -- 40 hours)

Mean Weight of Surface Scale, mg/cm^2

Without CI-2 in Fuel (a)

(1)	(1)	(1)	(1)	(2)	(1)	(2)	(1)
Coated	Coated	Coated	Coated	Bare	Bare	Bare	Bare
I-713C	IN-738	U-71C	U-700	I-713C	IN-738	U-700	U-710
2.81	3.42	4.28	5.97	10.58	12.11	18.48	24.72

With 0.1 % CI-2 in Fuel (b)

(1)	(1)	(1)	(1)	(2)	(2)	(1)	(1)
Coated	Coated	Coated	Coated	Bare	Bare	Bare	Bare
I-713C	U-710	IN-738	U-700	U-700	I-713C	IN-738	U-710
13.93	14.56	16.00	20.02	21.02	26.98	65.36	92.83

Notes:

Values in parentheses ( ) indicate number of observations.

(a) TSM = 10.99 (Bare$_1$ vs Bare$_1$)

TSM = 9.52 (Bare$_1$ vs Bare$_2$)

TSM = 7.77 (Bare$_2$ vs Bare$_2$)

TSM = 2.73 (Coated$_1$ vs Coated$_1$)

TSM = 8.01 (Coated$_1$ vs Bare$_1$)

TSM = 5.80 (Coated$_1$ bs Bare$_2$)

(b) TSM = 22.48 (Coated$_1$ vs Coated$_1$)

TSM = 17.70 (Coated$_1$ vs Bare$_1$)

TSM = 16.82 (Coated$_1$ vs Bare$_2$)

TABLE 11

COMPARISON OF WEIGHT OF SURFACE SCALE ON MDC-1 VS MDC-9 COATED SUPERALLOYS
(Row 2 -- 80 hours)

Mean Weight of Surface Scale, mg/cm^2

Without CI-2 in Fuel (a)

MDC-9	MDC-9	MDC-1	MDC-9	MDC-9	MDC-1	MDC-1	MDC-1
B-1900	MM-246	MM-246	MM-200	IN-100	B-1900	MM-200	IN-100
3.79	3.83	4.08	5.30	5.79	5.97	6.00	6.02

With 0.1 % CI-2 in Fuel (b)

MDC-9	MDC-9	MDC-1	MDC-9	MDC-9	MDC-1	MDC-1	MDC-1
IN-100	MM-246	IN-100	B-1900	MM-200	B-1900	MM-200	MM-246
7.67	10.79	12.32	12.80	14.26	20.13	24.41	24.96

Notes:

All values are single observations.

(a) TSM = 2.73

(b) TSM = 22.48

4.3.2. Composition of Surface Scale

X-ray diffraction analyses were made on samples of the surface scale resulting from exposure of the superalloys and superalloy-coating systems. The purpose of these analyses was to determine qualitatively if the presence of CI-2 in the fuel had an effect on scale composition to the end that such information might be useful in assessing if CI-2 has any predominant effect on the durability of the various superalloys and superalloy-coating systems.

A summary of the x-ray data for the neat and CI-2 treated fuel is shown in Table 12. Samples of the deposits represent a composite of the loosely-adhering surface scale from all exposed test specimens (i.e., for all time periods). The following observations are noted from the x-ray study:

(a) For the bare nickel-base superalloys (B-1900, Mar M-246, Mar M-200, IN-100, Inconel 713C, Udimet 700, IN-738, Udimet 710) strong patterns for crystalline NiO (bunsenite) are observed in the corrosion scale regardless of the presence of CI-2 in the fuel. This suggests that CI-2 has little or no effect on the rate of oxidation of nickel in the matrix of the base alloy.

(b) For the coated nickel-base superalloys, the effect of CI-2 on NiO appearance in the scale appears to be dependent on coating type and superalloy composition. In general, MDC-1 coating on nickel-base alloys, when exposed to CI-2, results in relatively weaker patterns for NiO than observed for the MDC-9 coated nickel-base alloys. This might suggest that there is a tendency for manganese to provide additional resistance to nickel oxidation when alloys are coated with MDC-1 coating. It is also noted that within the sensitivity of these measurements, which is about 2 weight per cent for the bunsenite patterns, that superalloys B-1900 and Mar M-246 in combination with either coating show no NiO in the scale when exposed to the fuel containing CI-2.

(c) Surface-scale samples of the bare nickel-base superalloys show strong patterns for nickel-, cobalt-, and chromium-spinel structures regardless of the presence of CI-2 in the fuel. With the exception of WI-52, the bare cobalt-base alloys (Mar M-509, Mar M-302, X-40, AiResist-215) do not show strong patterns for spinels, but strong patterns for two crystalline forms of the oxides of manganese (hausmannite, partridgeite) are observed. Similarly, all of the MDC-1 and MDC-9 coated alloys favor the appearance of manganese-oxide structures rather than the spinel structures of cobalt, nickel and chromium. It is also of interest that the relative intensities of the observed patterns (i.e., None, Doubtful, Weak, Strong) for manganese-oxide structures in the surface scale of the bare superalloys increase in the same order as their respective chromium concentrations. (See Table 45, Appendix 2.) These observations suggest that CI-2 in the fuel can cause variations in scale composition depending on superalloy composition and whether or not an aluminum-type coating is employed.

(d) The only indication in the surface scale that elements in the sea water have combined with metals in the test specimens is the appearance

TABLE 12

SUMMARY OF X-RAY DIFFRACTION ANALYSES OF SCALE RESULTING FROM HIGH-TEMPERATURE EXPOSURE OF SUPERALLOY TEST SPECIMENS TO FUEL CONTAINING MANGANESE ADDITIVE (ETHYL CI-2)

Super-alloy	Coating	X-Ray Diffraction Results for Scale Deposits[a]: Bunsenite (NiO) Neat	Bunsenite (NiO) CI-2	Mixed Spinel Structures Neat	Mixed Spinel Structures CI-2	Manganese Structures Neat	Manganese Structures CI-2	Unidentified Lines Neat	Unidentified Lines CI-2	Other Patterns Indicated Neat	Other Patterns Indicated CI-2
B-1900	None	S	S	S^{b}	S^{h}			S	W	NiF_2	NiF_2
MM-246	None	S	S	S^{b}	S^{h}			S	W		NiF_2
MM-200	None	S	S	S^{b}	S^{h}			S	W		
IN-100	None	S	S	S^{b}	S^{c}			W			
I-713C	None	S	S	S^{b}	S^{c}		$?^{f}$	S	W	NiF_2	NiF_2
U-700	None	S	S	S^{b}	S^{h}		W^{f}	W			
IN-738	None	S	S	$S^{c}, ?^{b}$	S^{d}		W^{f}, W^{g}	S			NiF_2
U-710	None	S	S	$S^{c}, ?^{b}$	S^{d}		W^{f}	W			
WI-52	None		?	S^{b}	S^{d}		W^{f}			CoO	
MM-509	None			W^{b}	$?^{e}$		S^{f}, W^{g}	W		CoO	
MM-302	None			S^{b}	$?^{e}$		S^{f}, W^{g}	S		CoO	
X-40	None			W^{b}	$?^{e}$		$S^{f}, ?^{g}$	S		CoO	
AR-215	None						S^{f}, W^{g}	W		CoO	
B-1900	MDC-1	S		S^{b}	$?^{b}$		S^{f}, W^{g}			NiF_2	
MM-246	MDC-1	S		S^{b}	$?^{b}$		S^{f}, W^{g}	S			
MM-200	MDC-1	S	W	S^{b}	$?^{b}$		S^{f}, W^{g}	S			
IN-100	MDC-1	S	S	S^{b}	$?^{b}$		S^{f}, W^{g}				
I-713C	MDC-1	S	W	S^{b}	$?^{b}$		S^{f}, W^{g}			NiF_2	
U-700	MDC-1	S	W	$S^{b,c}$	$?^{b}$		S^{f}, W^{g}				
IN-738	MDC-1	S		$S^{b}, ?^{c}$	$?^{b}$		S^{f}, W^{g}	S			
U-710	MDC-1	S	W	S^{b}	$?^{b}$		S^{f}, W^{g}	S			

(Continued on next page)

TABLE 12 (Cont'd)

X-Ray Diffraction Results for Scale Deposits[(a)]

Super-alloy	Coating	Bunsenite(NiO) Neat	Bunsenite(NiO) CI-2	Mixed Spinel Structures Neat	Mixed Spinel Structures CI-2	Manganese Structures Neat	Manganese Structures CI-2	Unidentified Lines Neat	Unidentified Lines CI-2	Other Patterns Indicated Neat	Other Patterns Indicated CI-2
B-1900	MDC-9	S		S^b	$?^b$		S^f,W^g	S		Al_2O_3	
MM-246	MDC-9	S			$?^b$		S^f,W^g	S		Al_2O_3,Co_3O_4	
MM-200	MDC-9	S	S		$?^b$		S^f,W^g	S		Co_3O_4	
IN-100	MDC-9	S	S	S^e	$?^b$		S^f,W^g	S		NiF_2	
I-713C	MDC-9	S	S	S^b	$?^b$		S^f,W^g	S		Al_2O_3,CoO,Co_3O_4	
U-700	MDC-9	S	S	S^c	$?^b$		S^f,W^g				
IN-738	MDC-9	S	S	S^c,W^b	$?^b$		S^f,W^g	S			NiF_2
U-710	MDC-9	S	W	S^c	$?^b$		S^f,W^g	S			
WI-52	MDC-9	...		...	$?^b$	...	S^f,W^g	...		...	
MM-509	MDC-9	...		...	$?^b$	...	S^f,W^g	...		...	
MM-302	MDC-9	...		...	$?^b$	...	$W^f,?^g$	...		...	
X-40	MDC-9	...		...	$?^b$	...	S^f,W^g	...		...	

a - Samples analyzed represent a composite of the loosely-adhering scale from all exposed test specimens (i.e., for all time periods) in a given superalloy-coating system
b - Unidentified cubic structure
c - Nickel chromite ($NiCr_2O_4$)
d - Cobalt chromite ($CoCr_2O_4$)
e - Nickel aluminite ($NiAl_2O_4$)
f - Hausmannite (Mn_3O_4)
g - Partridgeite (Mn_2O_3)
h - Possible cubic pattern: $(NiCrCo)_3O_4$

Code Designation:
S = Strong pattern observed
W = Weak pattern observed
? = Pattern not positively identified
...= Analysis not performed due to insufficient sample
Note: Blank spaces indicate no pattern was observed

in numerous instances of patterns believed to be NiF_2.

Because sodium sulfate is an important intermediate in mechanisms of hot corrosion, additional procedures were employed to determine its presence in the scale. From the x-ray diffraction study, no evidence of sodium sulfate was observed; however, it would not be detected if present in small quantities, or if it were tied up in the matrix of the scale as a solid solution. Accordingly, quantitative, chemical analyses for the presence of sodium and soluble sulfate ions were performed on composited samples resulting from exposure to the neat and manganese-treated fuels.

The following procedures were used in analyzing the composites for the respective ions: The composite was ground to a fine powder, then treated in a Soxhlet extractor with distilled water for 4 hours. Samples of the water extract were analyzed for sodium by flame emission. The remaining extract was treated with barium ions and the resulting precipitate (barium sulfate) was determined quantitatively by turbidimetric techniques.

A comparison of the results of these analyses resulting from operations with the neat and additive-treated fuels is shown in Table 13. Because the amount of available surface scale was considerably greater for specimens exposed to the fuel containing manganese additive, an attempt was made to determine if there was a difference in the behavior of cobalt-base alloys and nickel-base alloys with respect to sodium sulfate accumulation. The data show that sodium and sulfate ions are present in the scale of all composites. The molar ratio, which ranges from 2.4 to 2.7, is in good agreement with the 2.0 theoretical ratio for sodium sulfate. The amounts of sodium and sulfate ions in the scale of the cobalt-base alloys (exposed to fuel containing the manganese additive) are slightly less than for the scale from the nickel-base alloys; however, these are not considered significant. Similarly, the amounts of sodium and sulfate ions in the total scale from each fuel are also not considered significantly different. It is concluded from these observations that neither the manganese additive nor differences in superalloy composition have any marked effect on sodium sulfate deposition.

Confirmation that sodium sulfate is present in the corrosion scale from test specimens in these programs is not surprising and should be expected. Quigg and Schirmer (13) have shown from thermodynamic considerations that condensed sodium sulfate can exist at 15 atmospheres pressure and 1 ppm sea salt only at temperatures below about 1400 F. For this program the temperature at the test specimens range from 1000 to 2000 F during the 30-minute cycle. Moreover, the cycle was always terminated at 1000 F with sea salt addition. (Synthetic sea salt in this application contains dissolved sodium sulfate.) Thus, operationally and thermodynamically the test conditions were favorable for the appearance of sodium sulfate in the condensed state.

4.4. Metallography

4.4.1. Visual Appearance of Cleaned Specimens

The extent of metal loss by corrosive attack and the areas of coating breakdown were revealed more clearly after the surface scale was removed from the specimens by electro-cleaning. Visual inspection of the cleaned

TABLE 13

EFFECT OF MANGANESE ADDITIVE (CI-2) ON SODIUM SULFATE DEPOSITION

Fuel Description	Scale Description	Weight Per Cent In Scale Composite Na^+	Weight Per Cent In Scale Composite $SO_4^=$	Molar Ratio, Na/SO_4
Base[(a)] + Mn-Additive	Composite from Ni-Base Alloys	1.20	1.80	2.7
	Composite from Co-Base Alloys	0.79	1.30	2.4
	Total Composite (Weighted Avg.)	1.11	1.69	2.7
Base[(a)]	Total Composite	0.84	1.44	2.4

(a) Base = Phillips Alkylate (Base Oil No. 1) containing 0.04 wt% sulfur

specimens disclosed that the attack on the bare superalloys is quite uniform over the entire surface of the test specimens. Hot corrosion seems to progress steadily with increasing exposure time, but at a higher rate on specimens of superalloys with lower chromium content. Superficially, specimens of low-chromium superalloys appear smooth and bright; but,with increasing chromium content their surfaces become porous and dirty—a condition associated with a surface layer of partially oxidized metal. When it occurs, coating breakdown is quite random over the entire surface of the specimen; however, after penetration of the coating, the attack progresses more rapidly and produces a non-uniform surface which becomes most evident on specimens of superalloys with lower chromium content. Thus, by superficial appearance, the specimens are divided into bare and coated superalloys, and each of these groups are further subdivided by chromium content.

These differences in surface appearance of the various turbine-blade materials following their exposure and cleaning are evident in the composite, Figures 6 through 25. It should be noted that, in these figures, the specimens of each test material are arranged in order of increasing exposure time. As a result, the steady progress of hot corrosion with exposure time can be seen, despite the fact that they are different specimens. Also, these figures are arranged to show the superalloys, and their coating systems, in order of increasing chromium content. In general, this results in an ordering of increasing resistance to hot corrosion. The smooth and bright surface of the low-chromium superalloys is shown in Figures 6 (B-1900), 8 (Mar M-246), 10 (Mar M-200), and 12 (IN-100). The porous and dirty surface of the high-chromium superalloys is shown in Figures 18 (IN-738) and 20 (Udimet 710) for the nickel-base alloys, and in Figures 22 through 25 for the cobalt-base alloys. The random penetration of the aluminum-rich coating (Misco MDC-1) and the aluminum-chromium-rich coating (Misco MDC-9) is shown in Figures 7, 9, 11, and 13 for the low-chromium superalloys, where it was followed by localized attack. The more uniform attack which follows coating breakdown on the high-chromium superalloys is shown in Figures 19 and 21 for the nickel-base alloys, and in Figures 22 through 25 for the cobalt-base alloys.

The specimens are displayed in Figures 6 through 25 to facilitate comparison between the base-line test and the test with 0.1 per cent by volume of Ethyl CI-2 added to the fuel. Several observations were made from the visual appearance of these cleaned specimens, with respect to the effect of manganese addition to the aggressive-thermal environment, which are as follows:

(a) The manganese additive <u>increased</u> the hot corrosion of bare superalloys. This was most evident on the high-chromium nickel-base superalloys shown in Figures 18 (IN-738) and 20 (Udimet 710).

(b) The manganese additive <u>decreased</u> the hot corrosion of coated superalloys. This was most evident on the low-chromium nickel-base superalloys with an aluminum-rich coating (Misco MDC-1) shown in Figures 7 (B-1900), 9 (Mar M-246), and 11 (Mar M-200).

These general visual impressions were confirmed by the more precise evaluations of metal damage which will be detailed later in this report.

4.4.2. Evaluation of Metal Damage

There is difficulty in evaluating the extent of damage to the metal specimens when either localized or subsurface corrosion is present. In general, the performance of low-stress parts, such as turbine vanes, deteriorates as they loose their shape from surface corrosion; but, subsurface corrosion can lead to the complete destruction of high-stress parts, such as turbine blades. Two different types of measurement, loss-in-weight and depth-of-penetration, have been used to evaluate the extent of metal damage by hot corrosion. Both methods require some metallographic examination of specimens, but they differ appreciably in the extent of this requirement. Both methods suffer from inherent weaknesses.

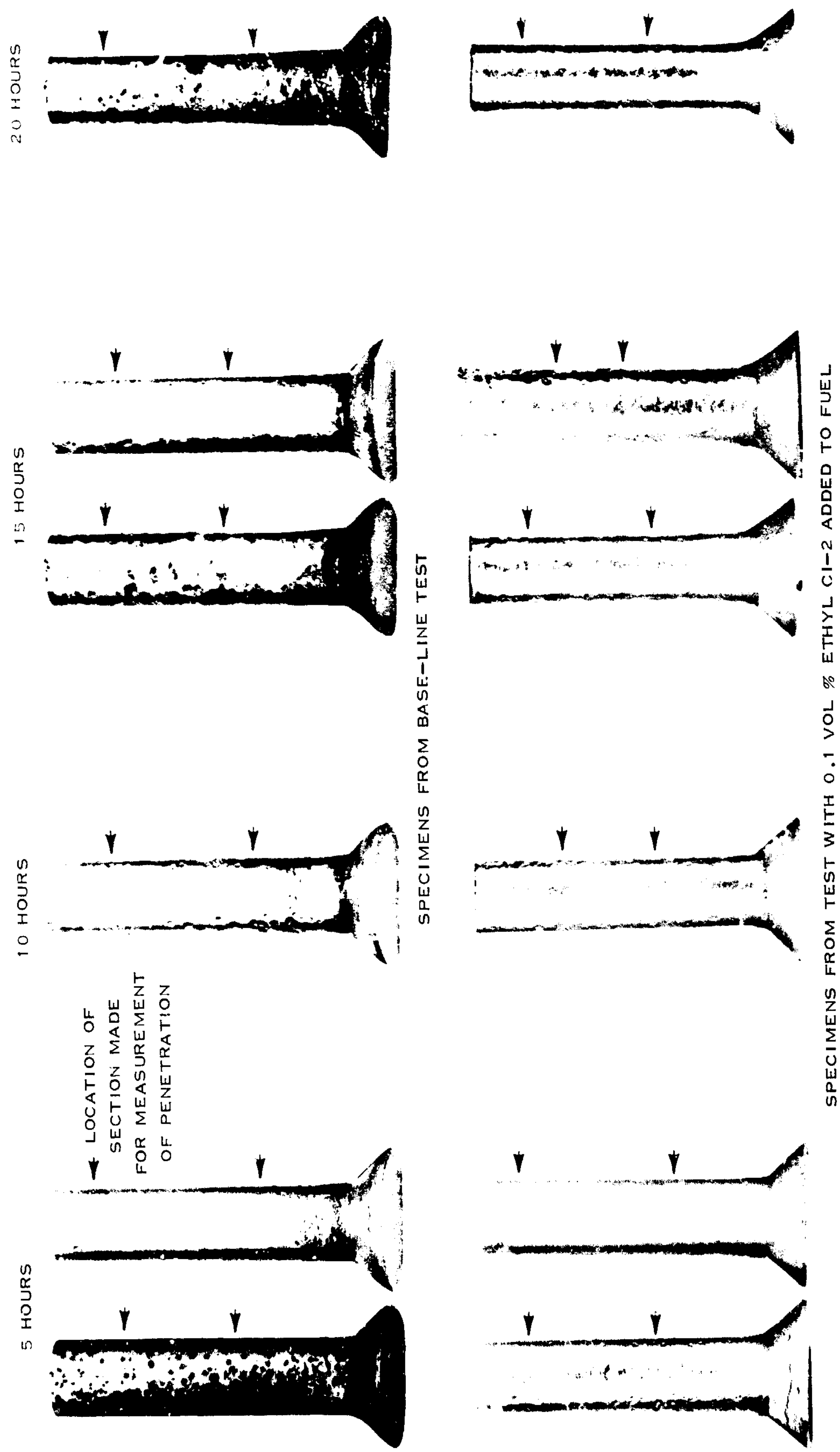
The weight-loss method assumes a uniform attack over the surface of the specimen, with the absence of subsurface deterioration by deep sulfide penetration or intergranular oxidation. Also, it requires complete removal of corrosion products from the specimen without further damage to its surface. Both of these potential faults in the weight-loss method can be aggravated by the application of coatings to the superalloy specimens, and such materials were employed extensively in this investigation.

The penetration method avoids the weaknesses in the weight-loss method by using metallographic cross-sections; however, it assumes that the location of maximum subsurface deterioration, for taking the cross-section, can be identified by a visual inspection of the specimen's exterior. Also, it presumes that precise measurements of penetration can be made with a reasonable expenditure of time and effort. The demand for metallography by the penetration method can be quite formidable in a program having a large productivity of specimens, such as in this investigation.

Since measurements of weight-loss are simpler, faster, more economical, and less subjective (selection of locations for cross-sectioning specimens), they should be used to evaluate the extent of metal damage whenever feasible. However, the validity of using weight-loss data for evaluation of hot-corrosion attack should be established by showing the absence of any unusual amount of subsurface deterioration. This can be done by metallographic examination of a few representative specimens of each superalloy, or superalloy-coating system, selected from over the range of exposure conditions.

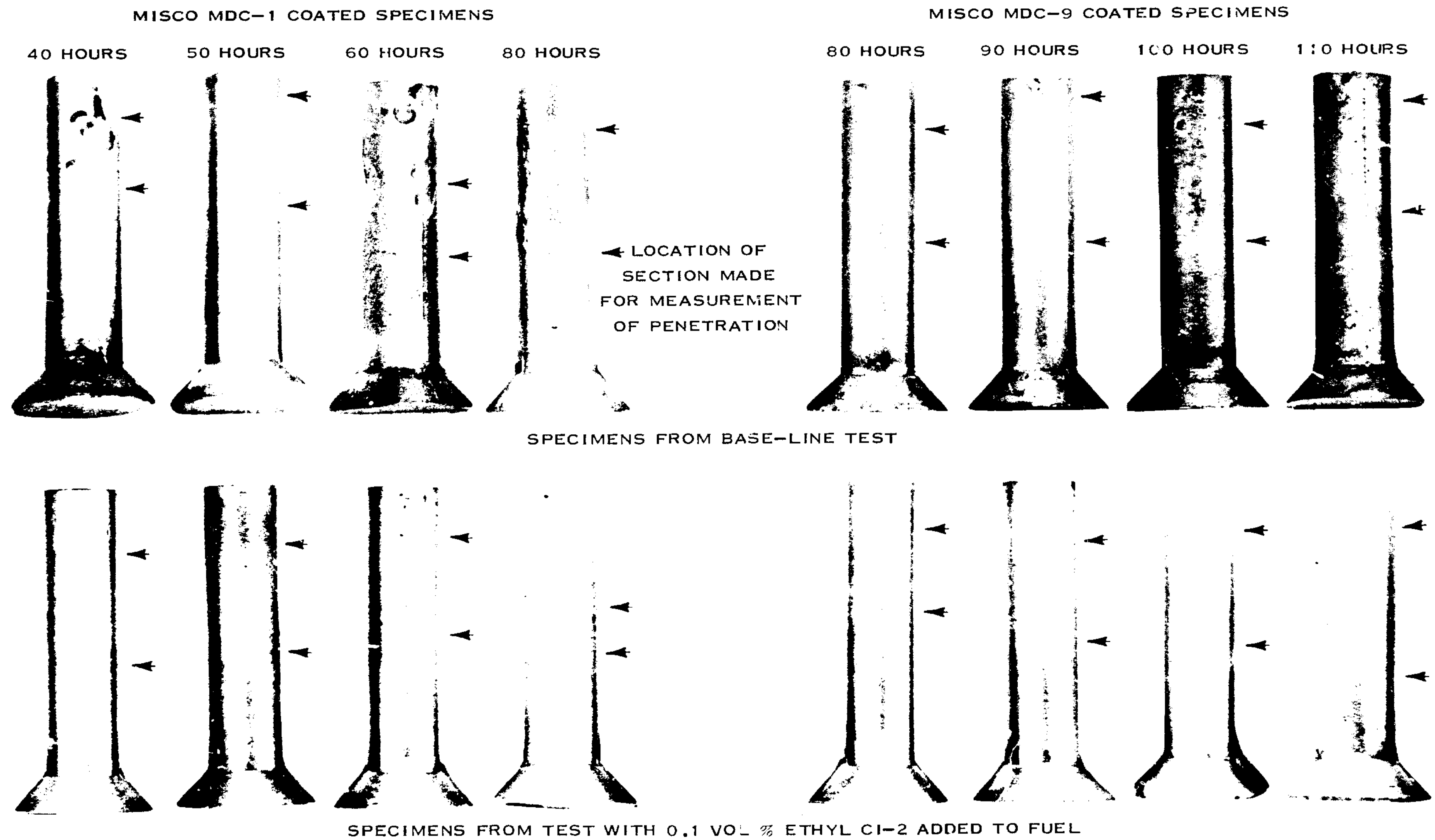
4.4.3. Nature of Corrosive Attack

Previous metallographic examinations (12, 13, 14) have shown hot corrosion to advance on a broad front, without deep inter-crystalline penetration by sulfides or oxides. The attack on the base alloy has been led by penetration of randomly dispersed, light-grey, globules of metallic sulfides. Their formation has been associated with changes in the surface composition of the alloy, which were characterized by chromium depletion. Rapid oxidation of the weakened layer of alloy has followed. The depth of subsurface deterioration has ranged from less than one to a maximum of about five mils.



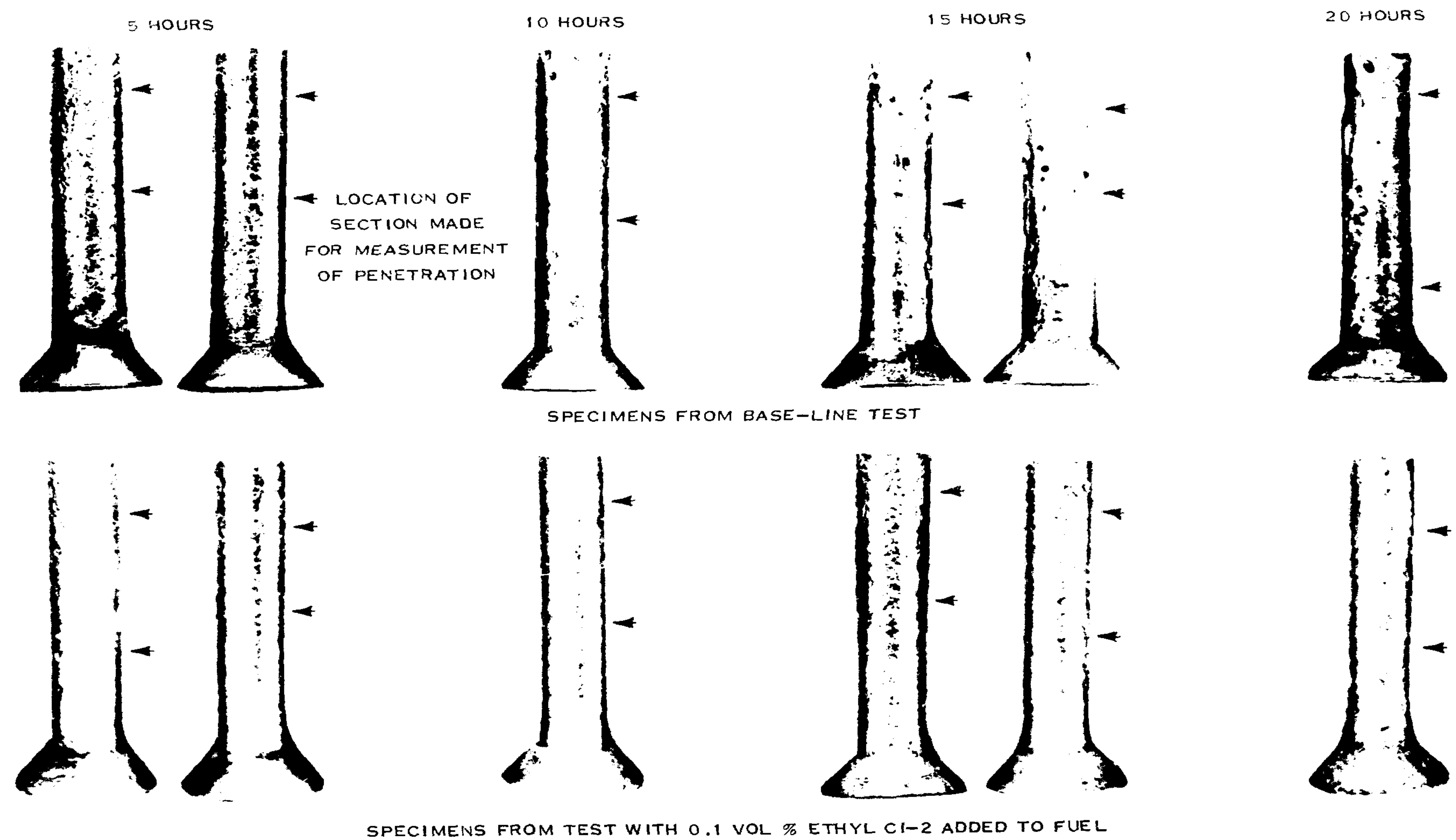
ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

FIGURE 6
COMPARISON OF BARE B-1900 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR



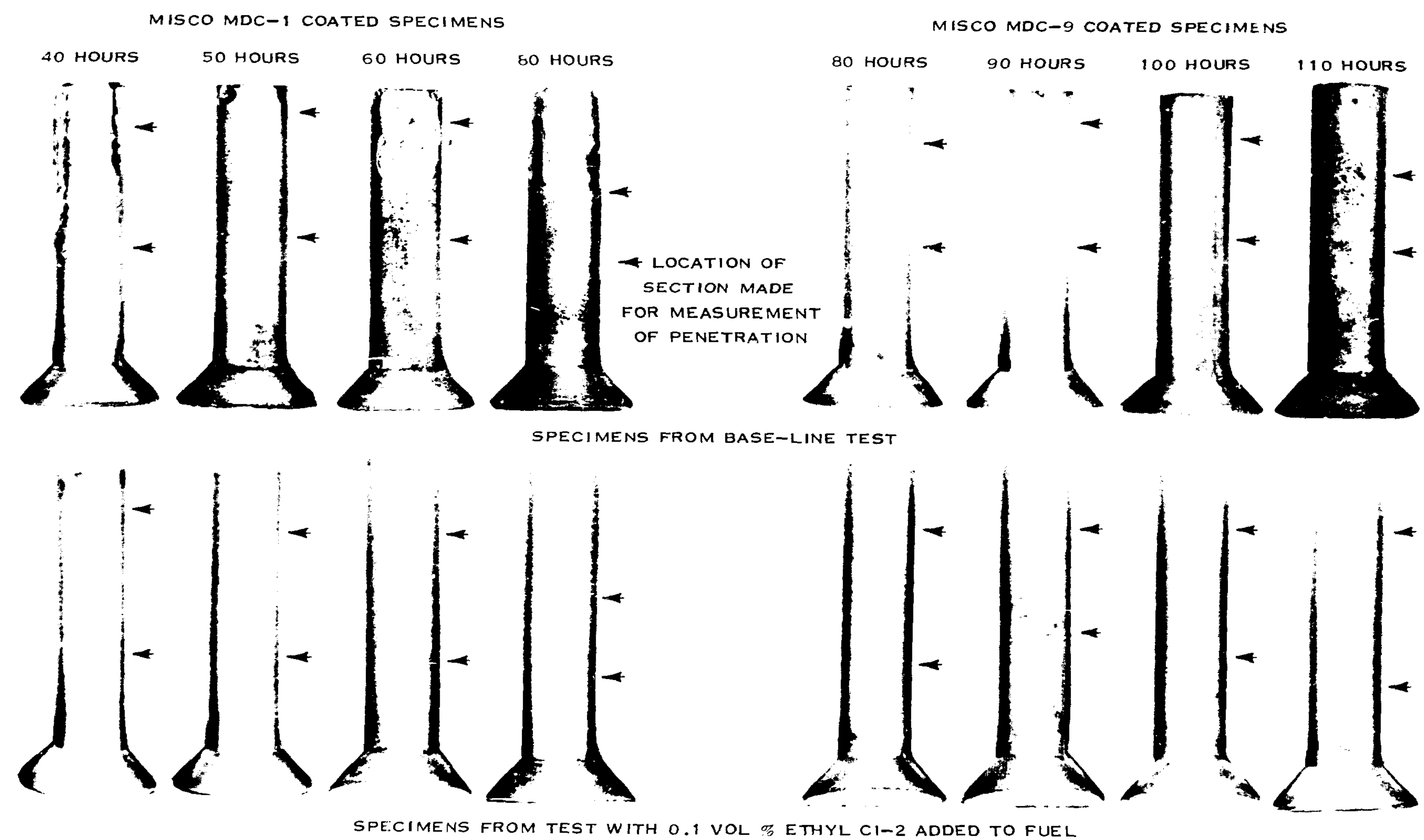
ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

FIGURE 7
COMPARISON OF COATED B-1900 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR



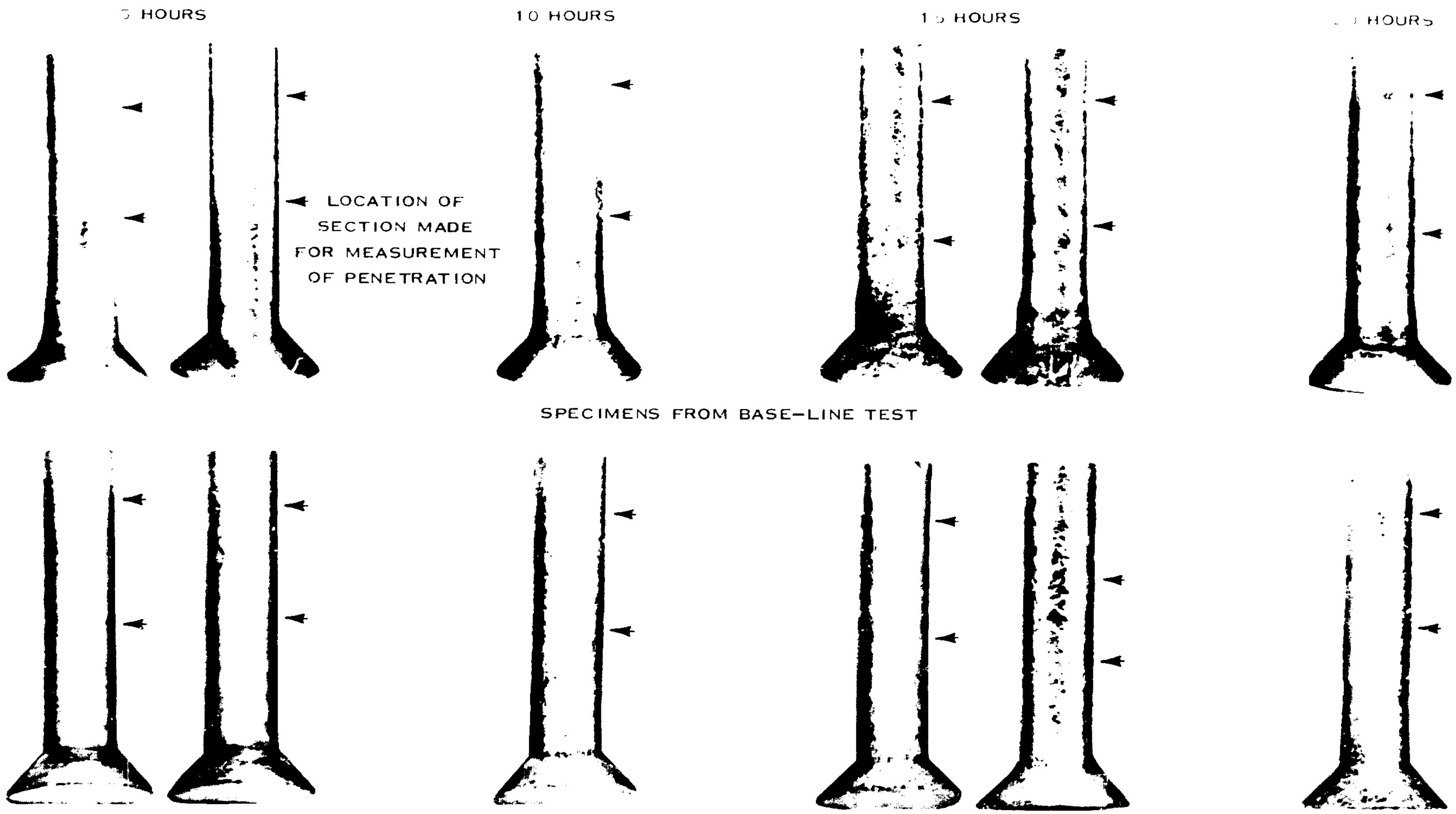
ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

FIGURE 8
COMPARISON OF BARE MM-246 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR



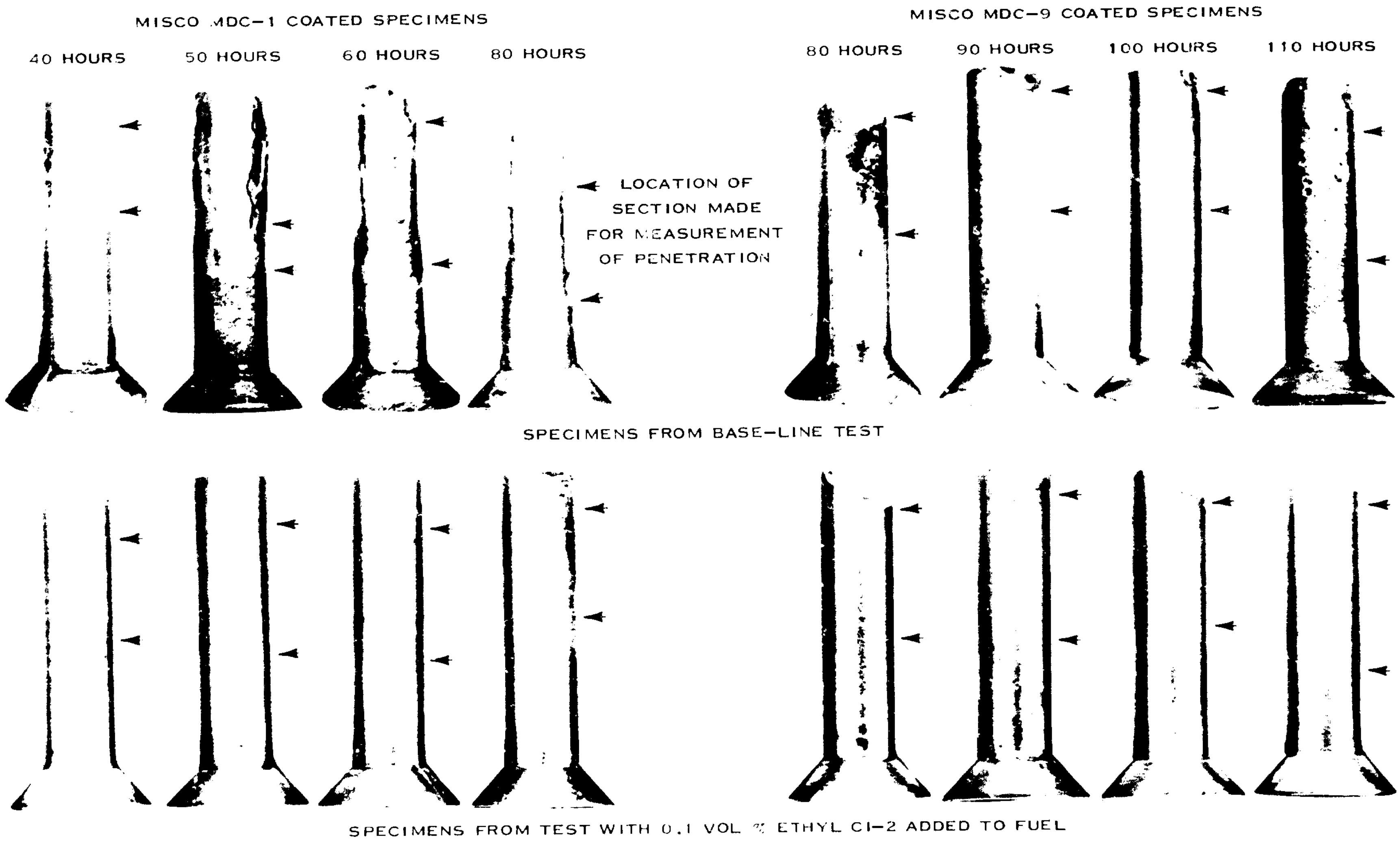
ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

FIGURE 9
COMPARISON OF COATED MM-246 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR



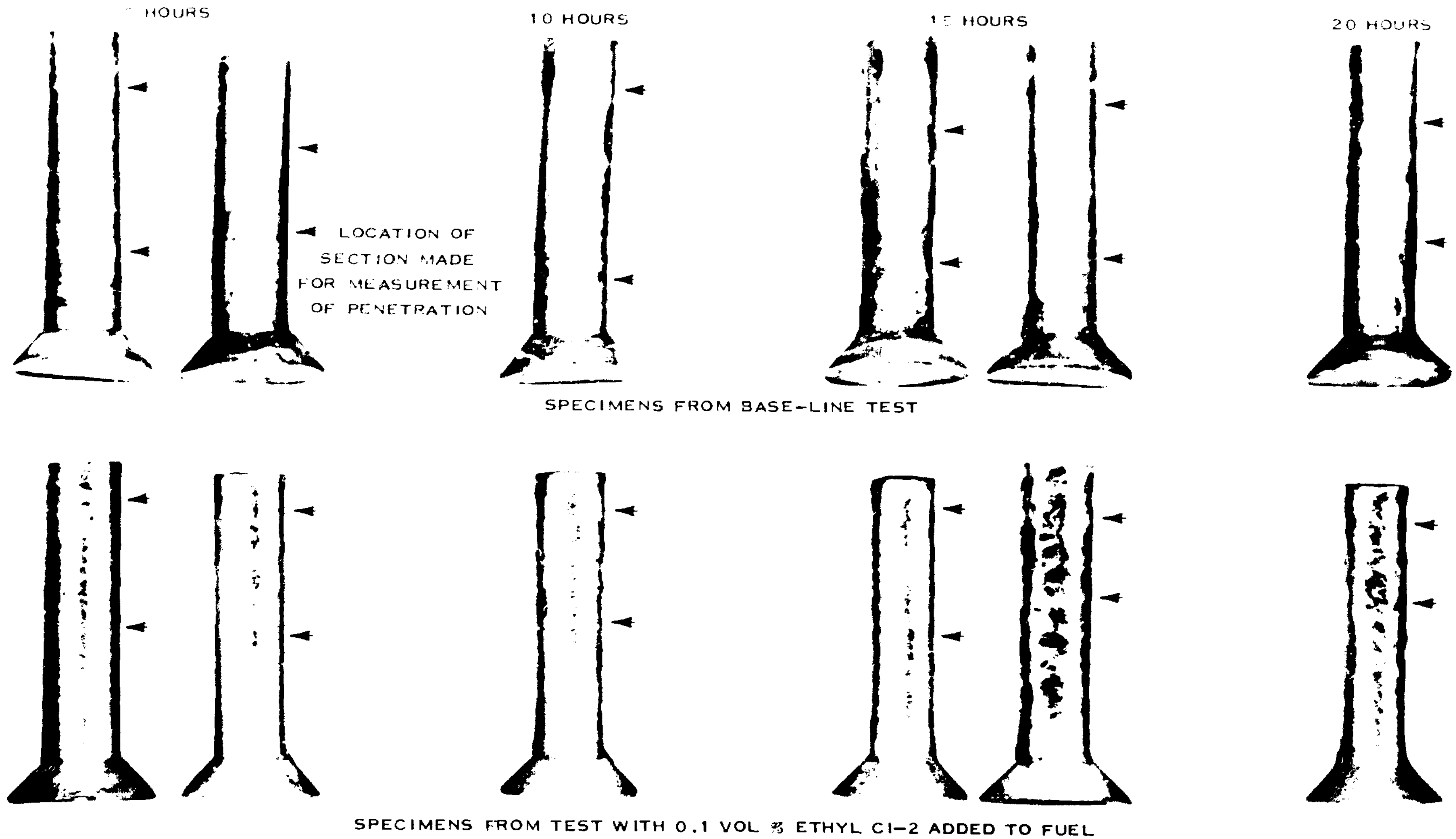
ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

FIGURE 10
COMPARISON OF BARE MM-200 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR



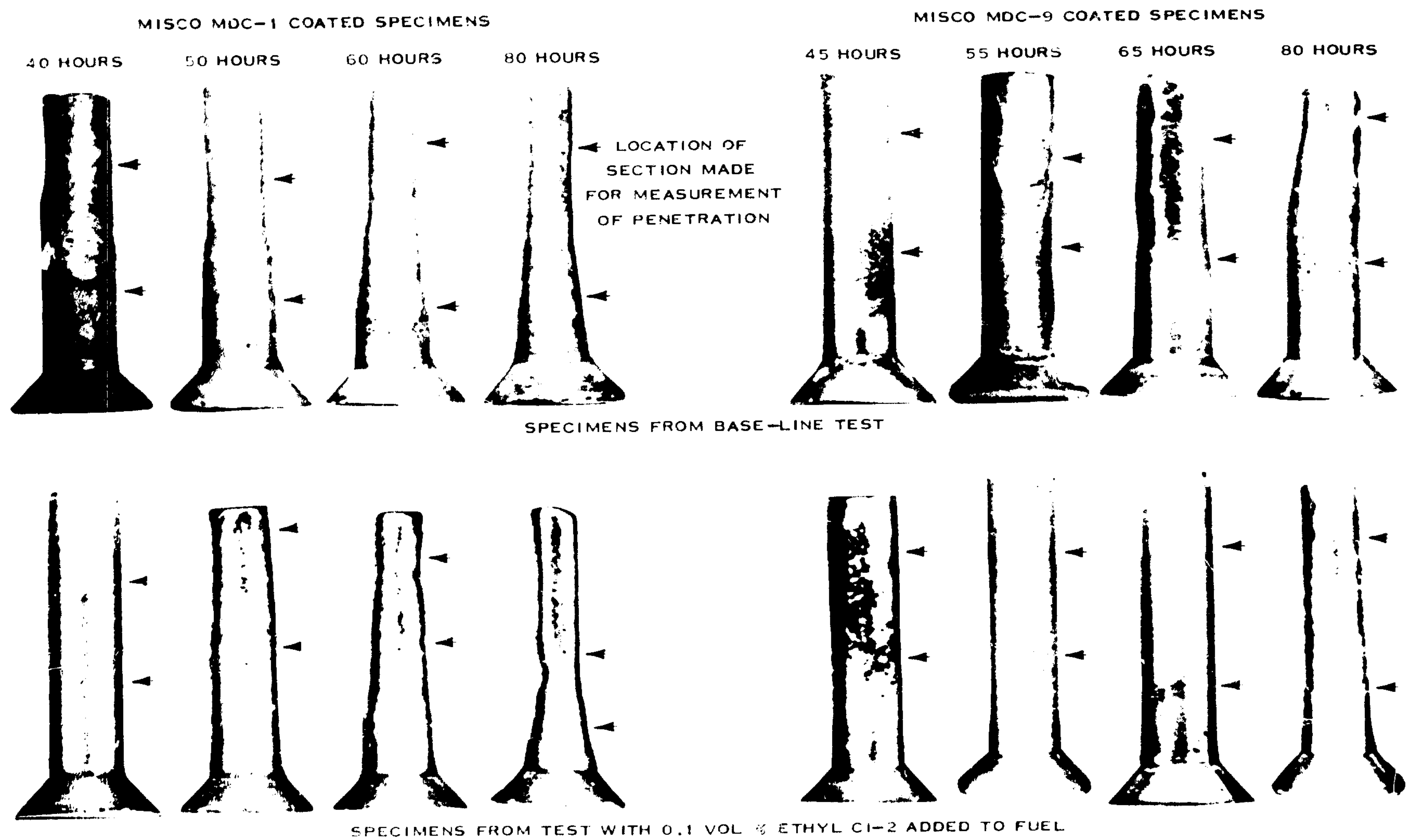
ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

FIGURE 11
COMPARISON OF COATED MM-200 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR



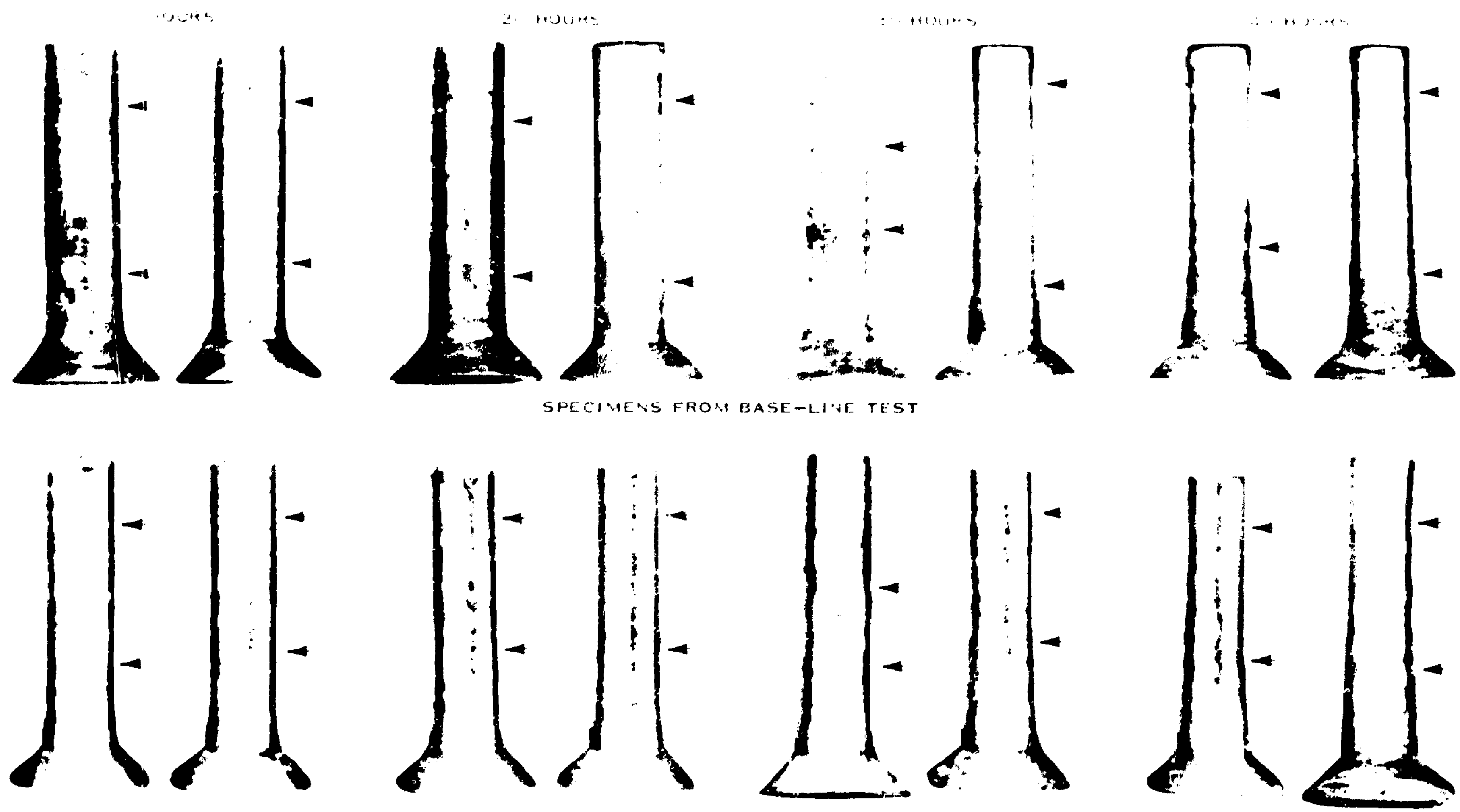
ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

FIGURE 12
COMPARISON OF BARE IN-100 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR



TRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

FIGURE 13
COMPARISON OF COATED IN-100 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR

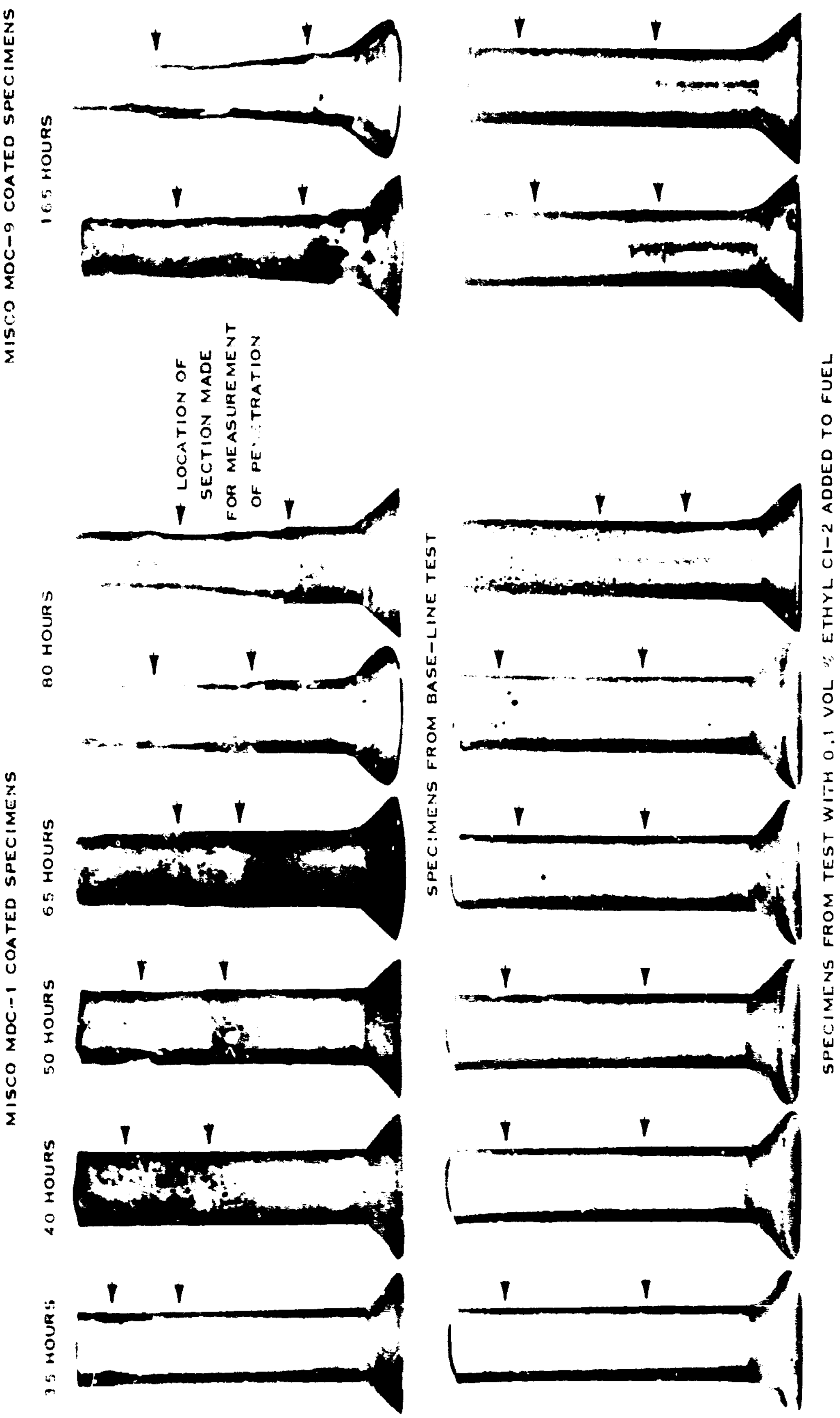


◄ LOCATION OF SECTION MADE FOR MEASUREMENT OF PENETRATION

ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

FIGURE 14

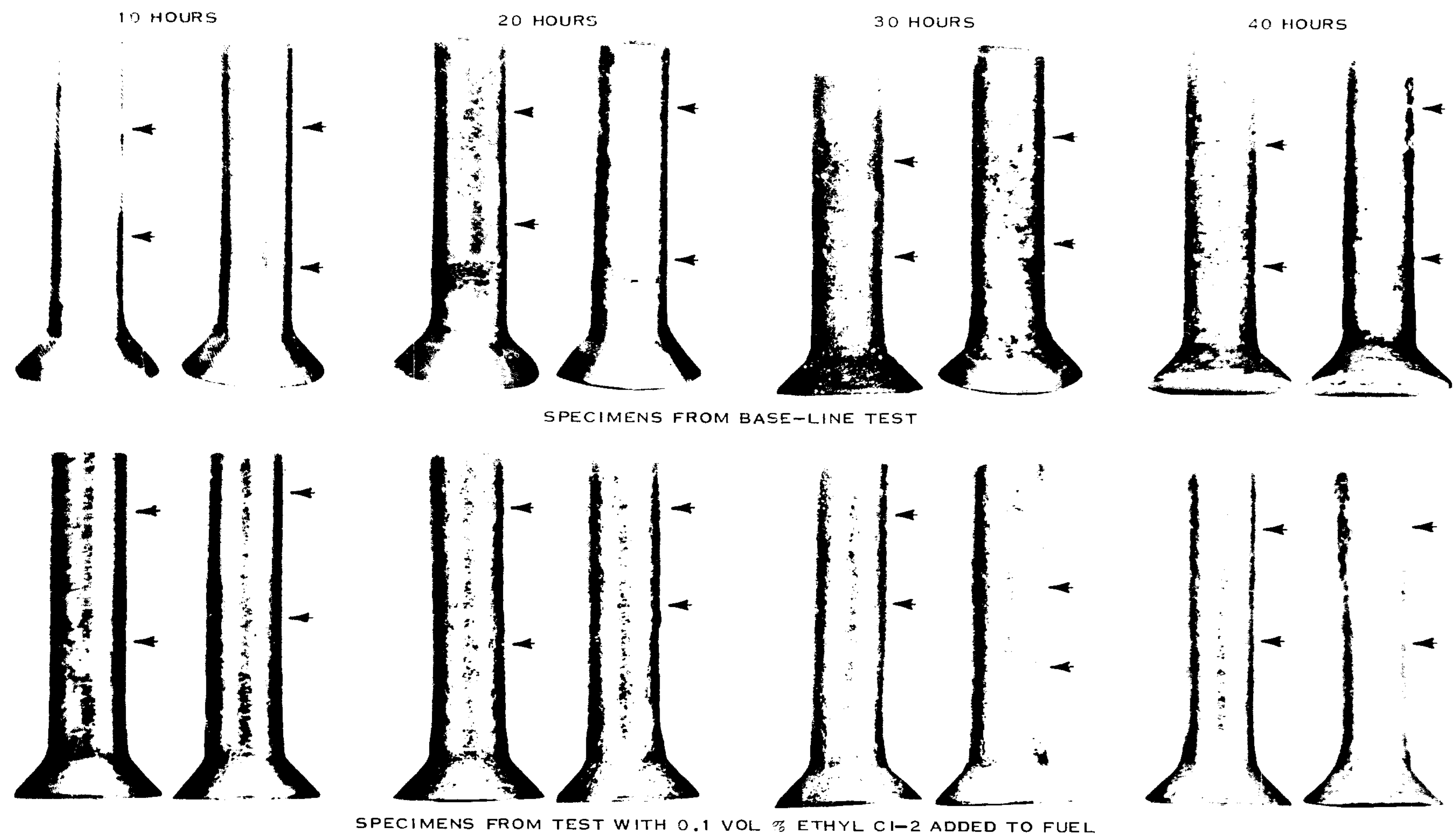
COMPARISON OF BARE I-713C SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR



ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

FIGURE 15

COMPARISON OF COATED I-713C SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR

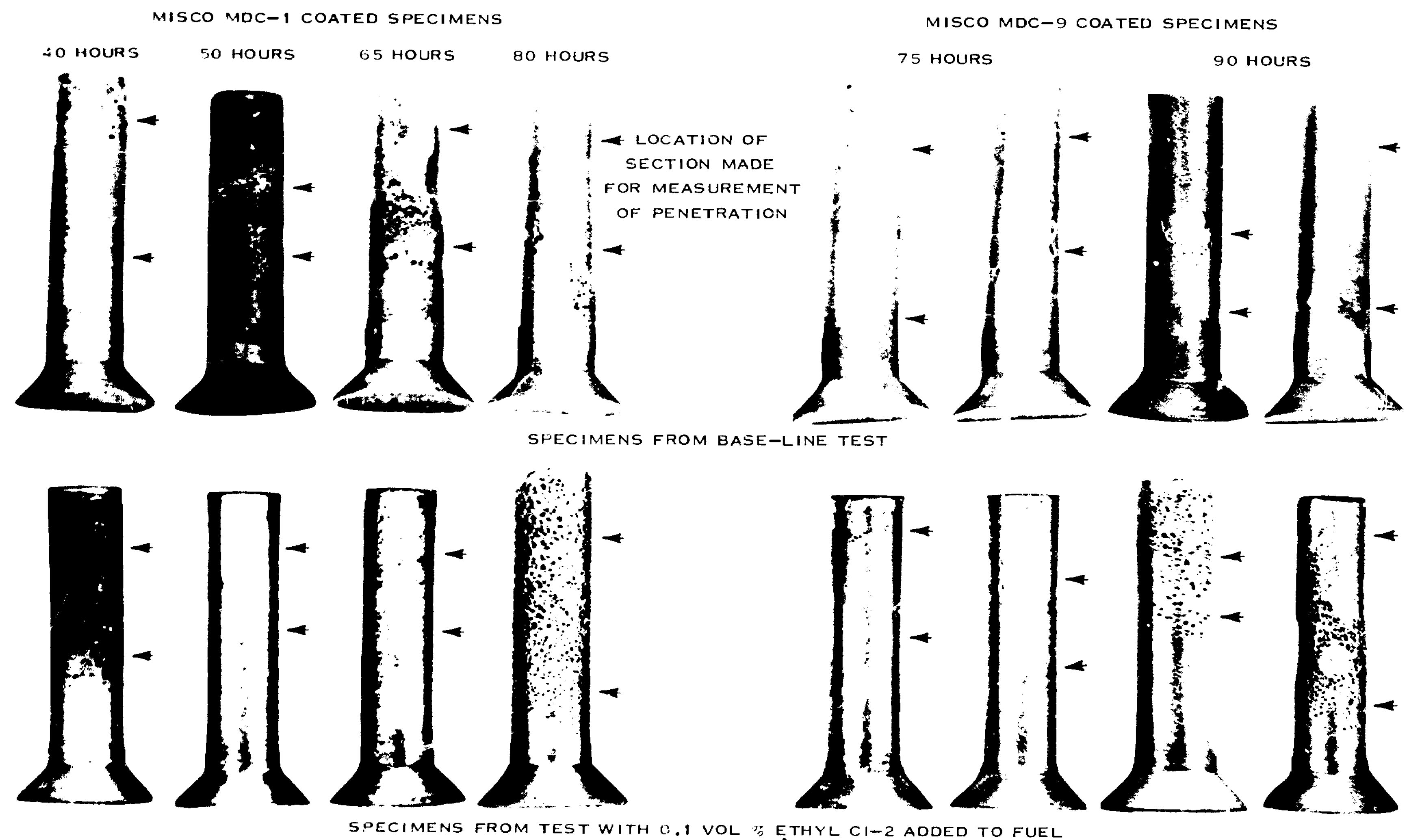


◄ LOCATION OF SECTION MADE FOR MEASUREMENT OF PENETRATION

ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

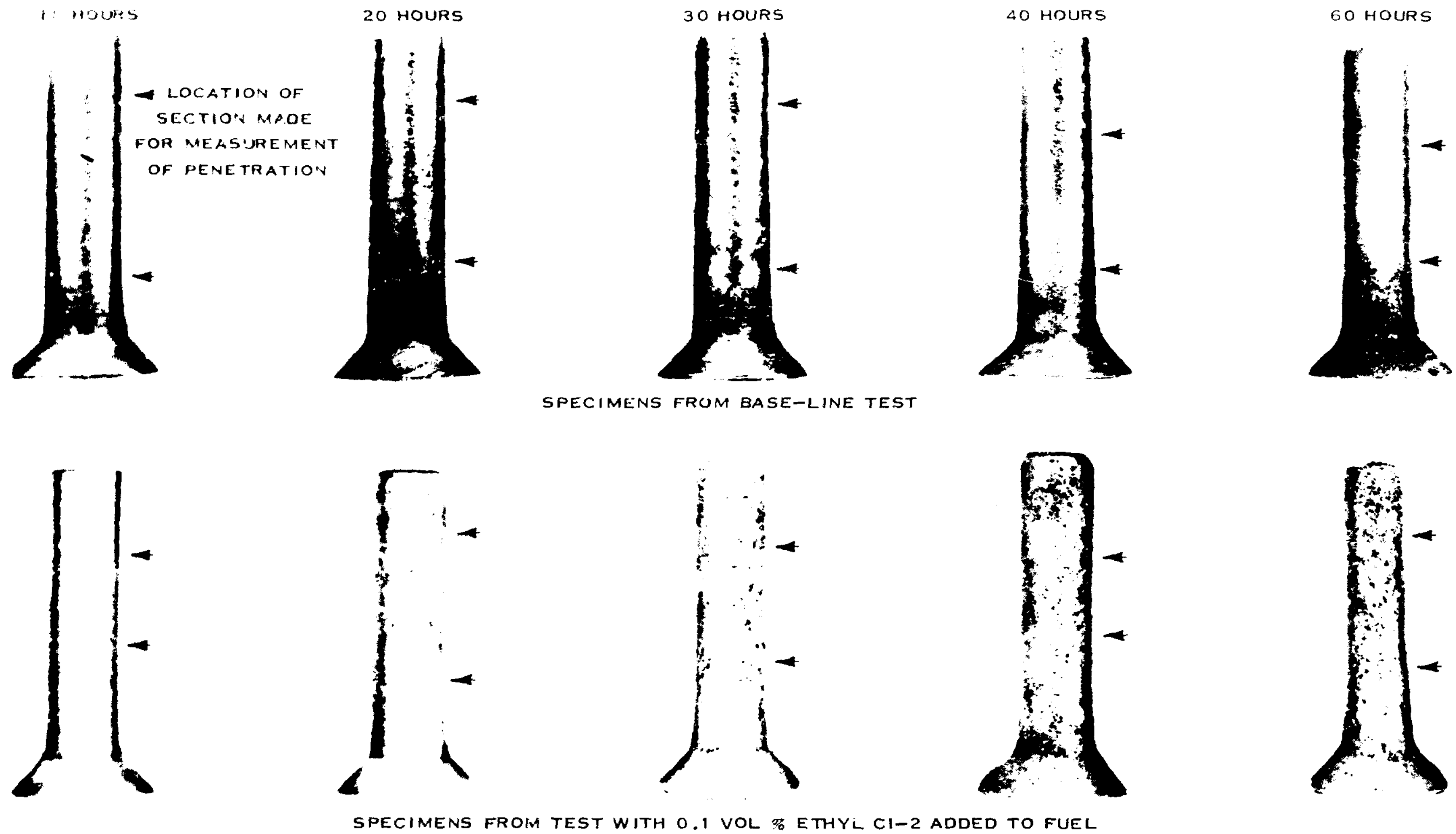
FIGURE 16

COMPARISON OF BARE U-700 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR



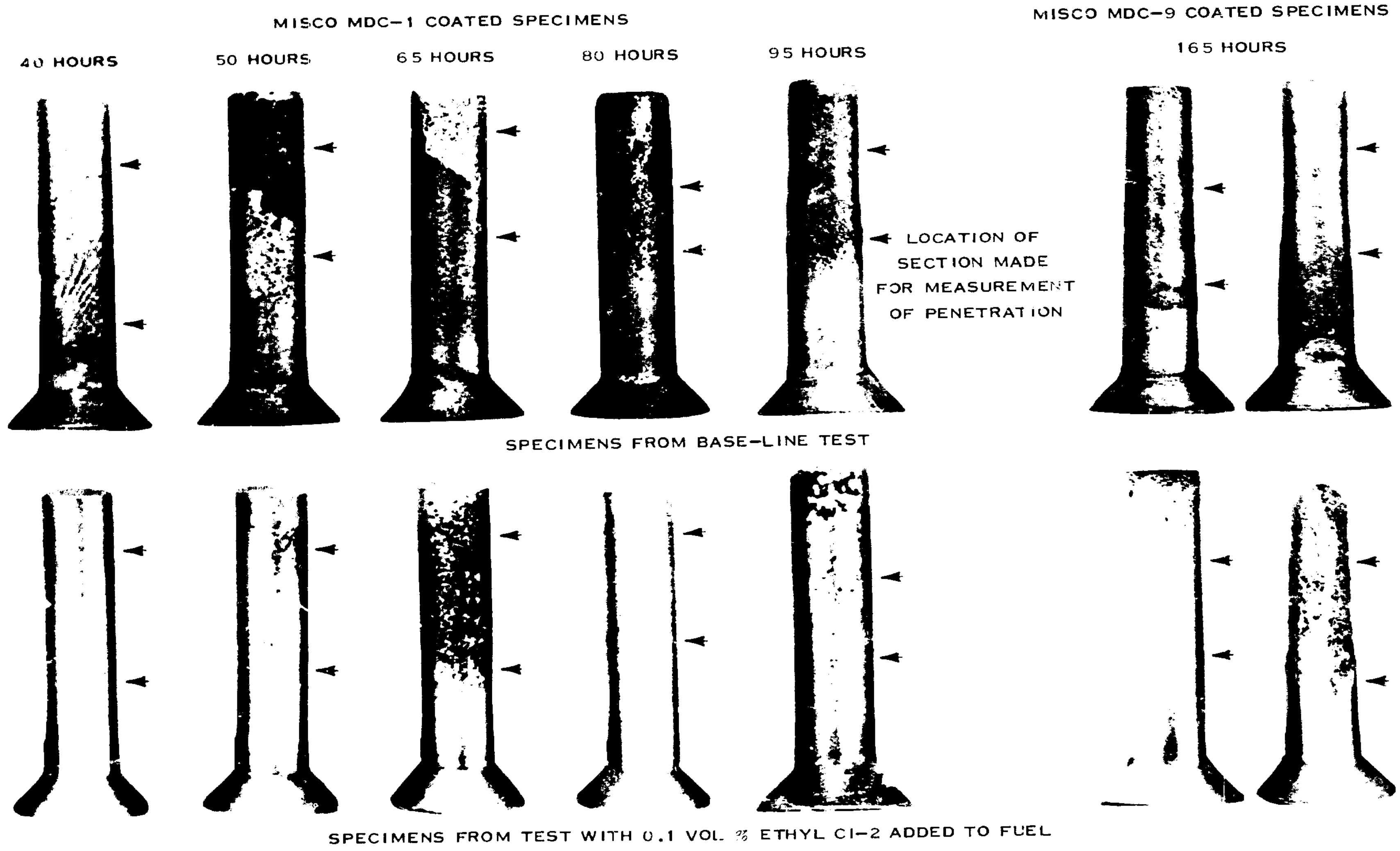
ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

FIGURE 17
COMPARISON OF COATED U-700 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR



ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

FIGURE 18
COMPARISON OF BARE IN-738 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR



ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

FIGURE 19
COMPARISON OF COATED IN-738 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR

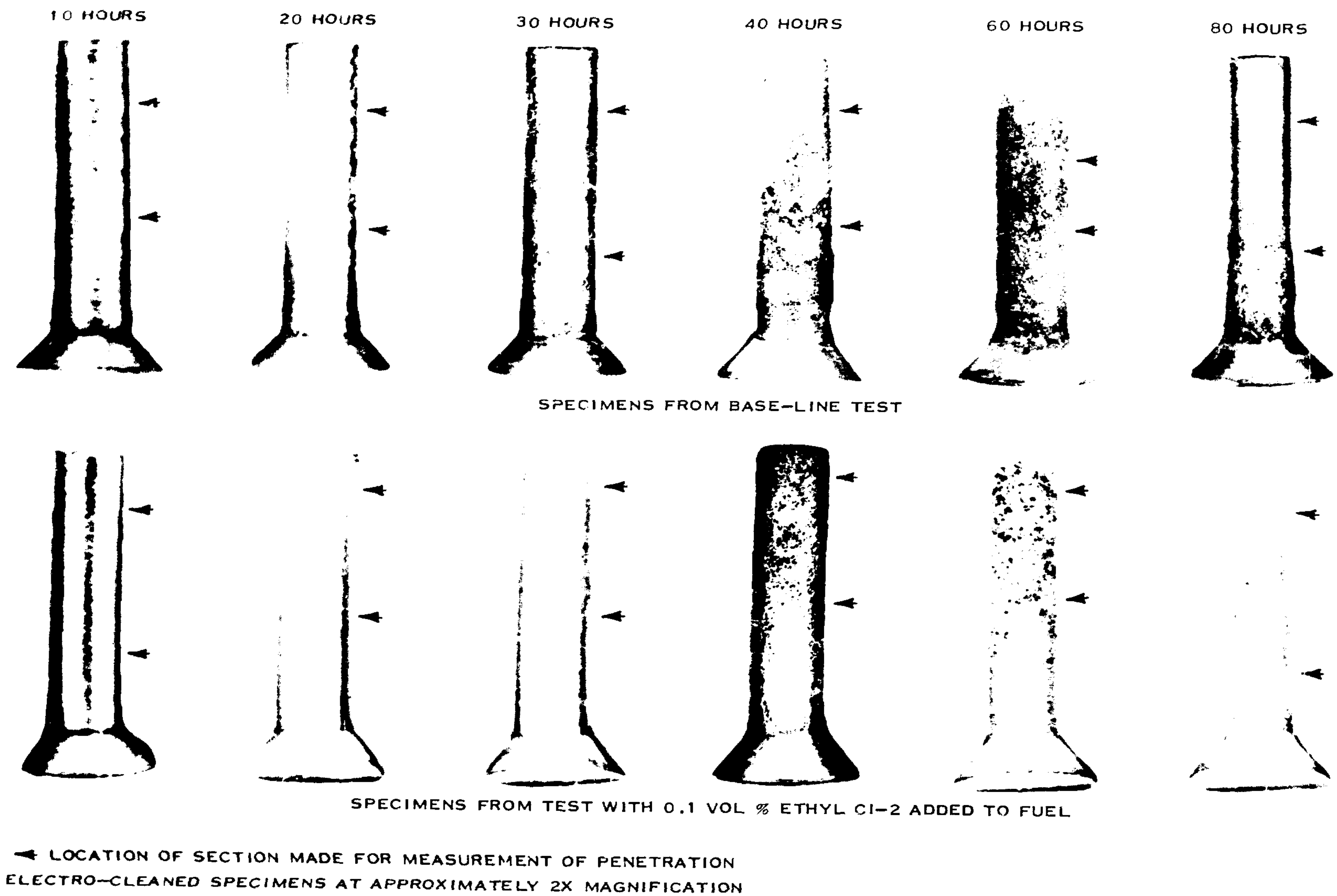
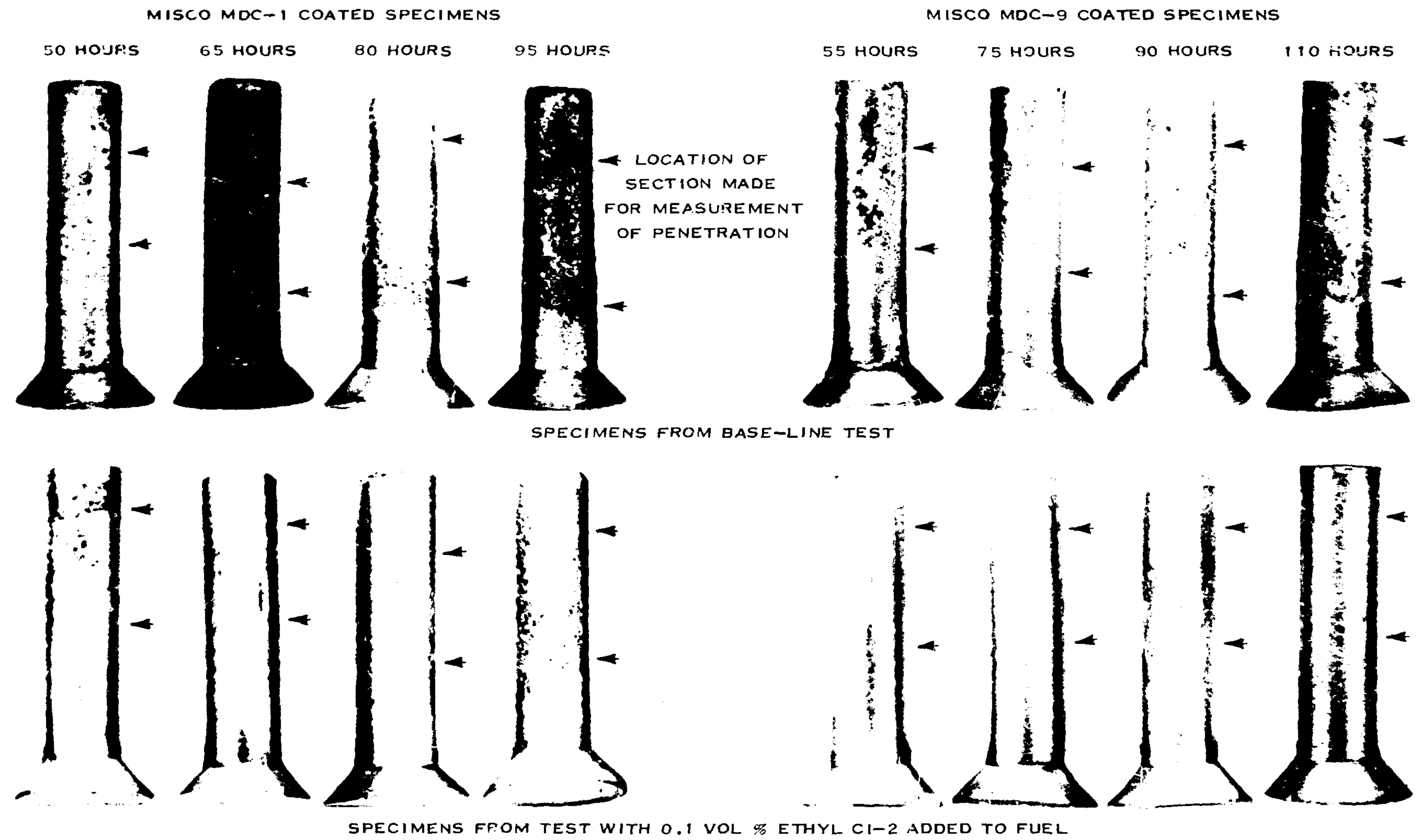
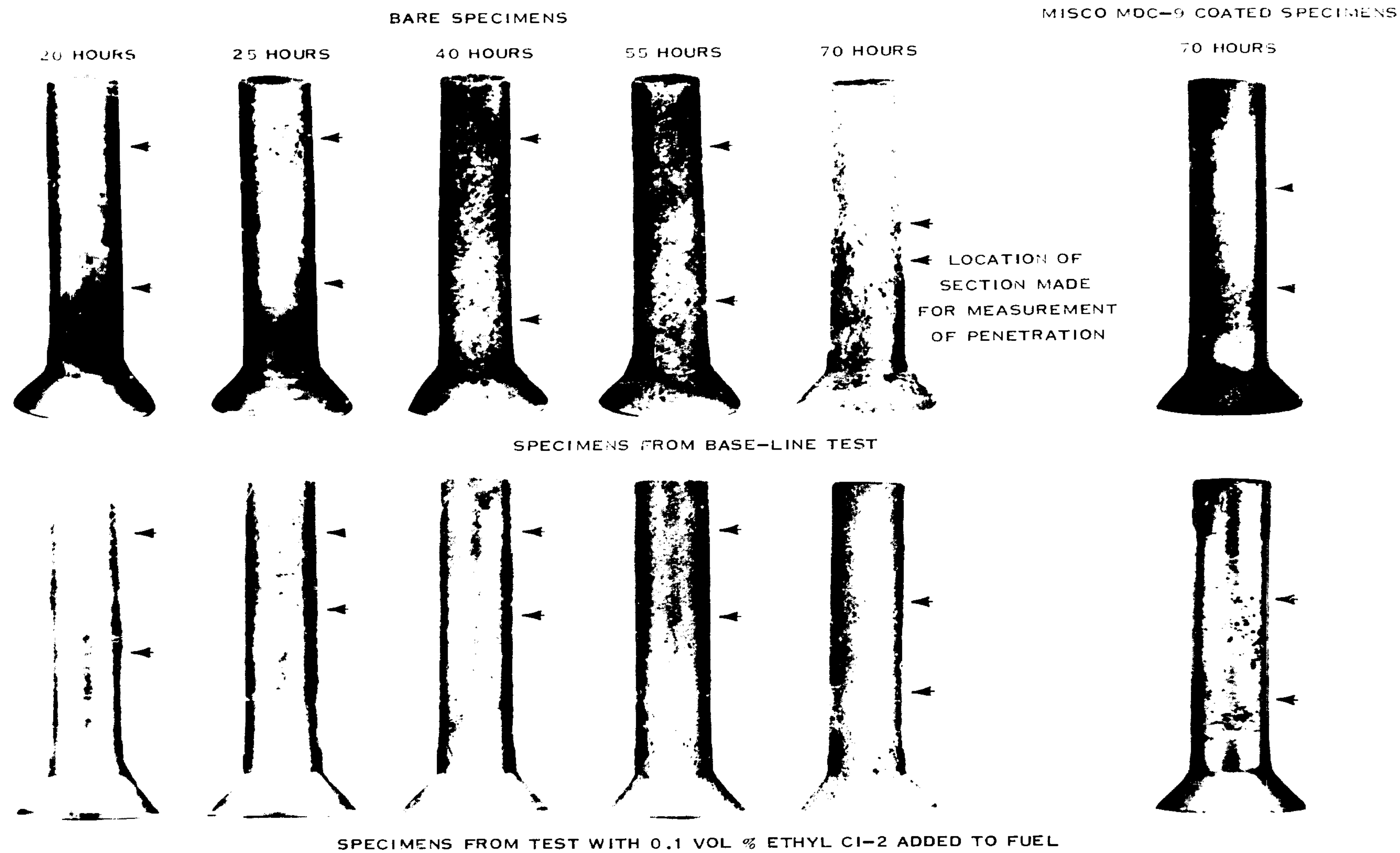


FIGURE 20
COMPARISON OF BARE U-710 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR



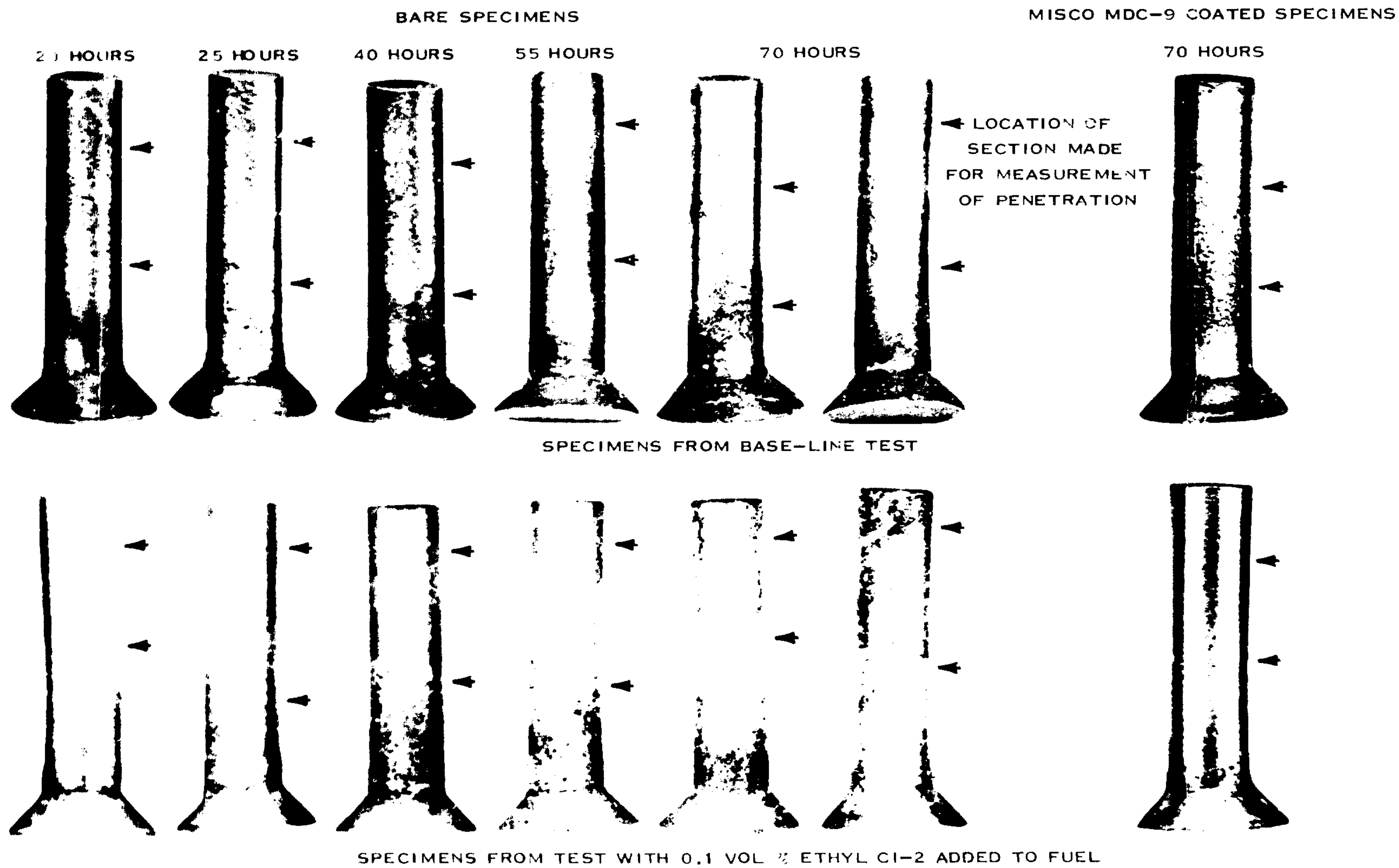
ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

FIGURE 21
COMPARISON OF COATED U-710 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR



ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

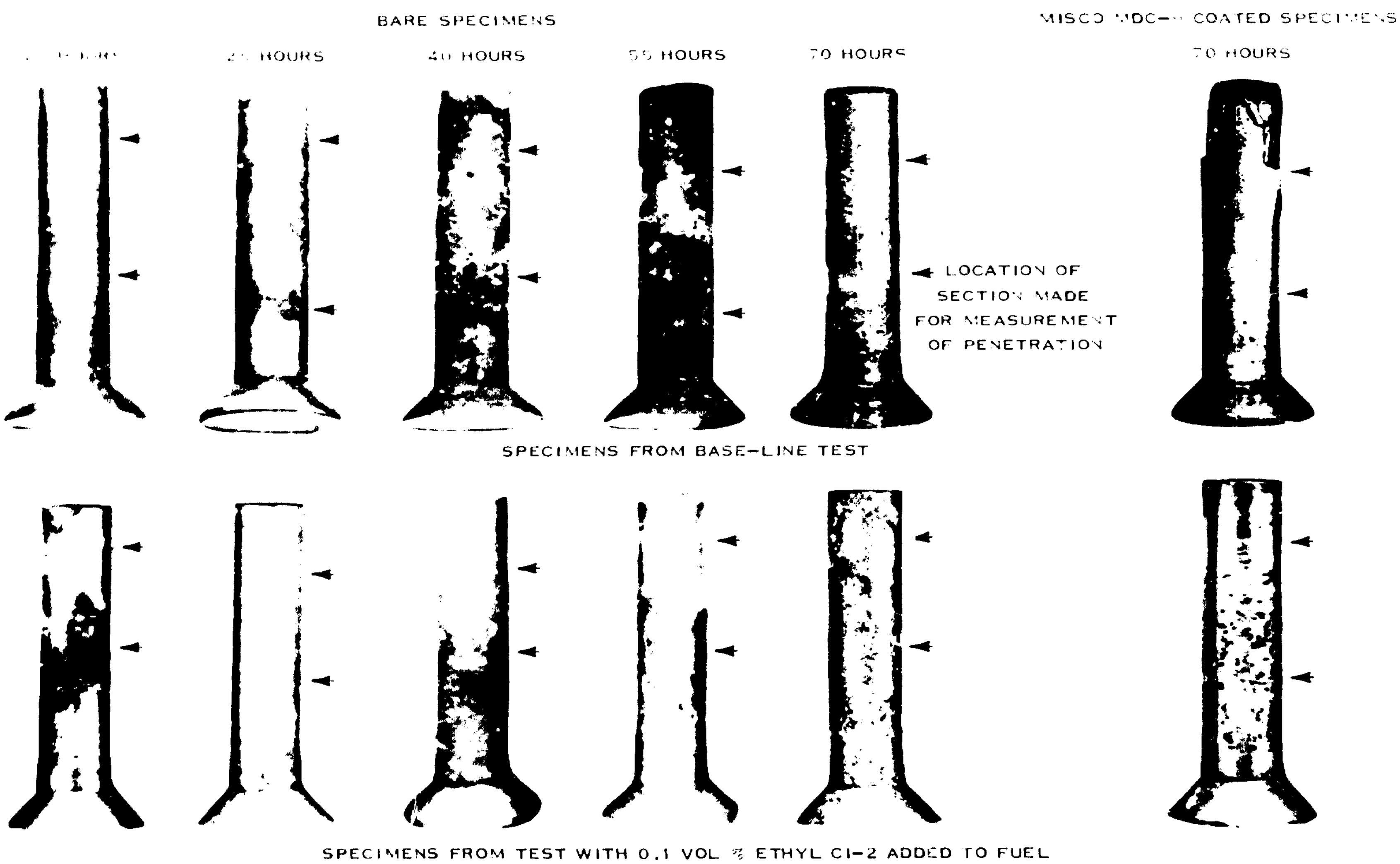
FIGURE 22
COMPARISON OF WI-52 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR



ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

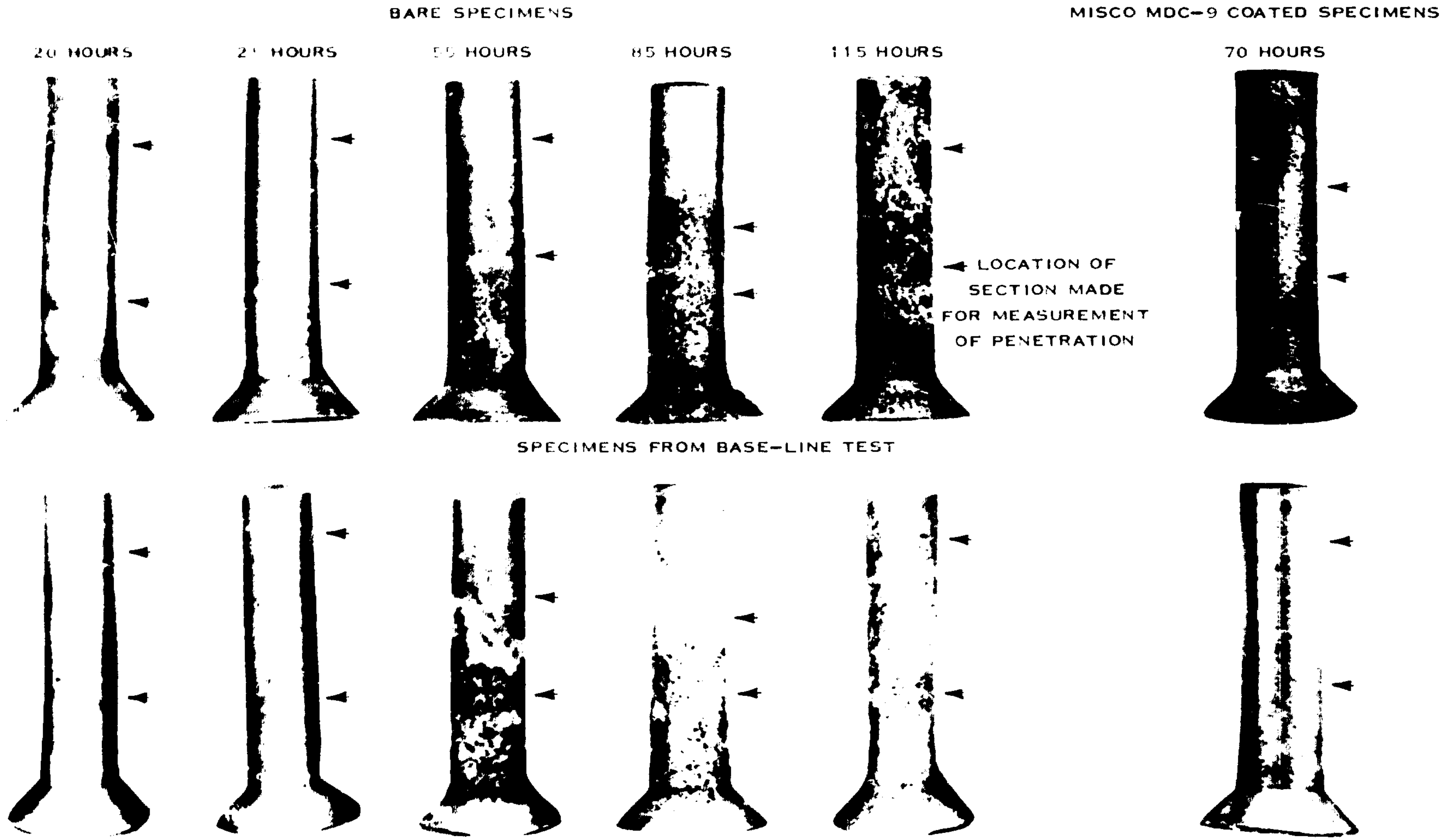
FIGURE 23

COMPARISON OF MM-509 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR



ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

FIGURE 24
COMPARISON OF MM-302 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR



SPECIMENS FROM TEST WITH 0.1 VOL % ETHYL CI-2 ADDED TO FUEL

ELECTRO-CLEANED SPECIMENS AT APPROXIMATELY 2X MAGNIFICATION

FIGURE 25
COMPARISON OF X-40 SPECIMENS AFTER EXPOSURE IN PHILLIPS TURBINE SIMULATOR

A linear relationship has been found between measurements of specimens weight-loss and corrosion penetration. These observations have served to justify our use of specimen weight-loss data as a valid measurement of metal damage during previous investigations.

During the present investigation, the general mode and intensity of hot-corrosion attack sustained by specimens exposed in the Turbine Simulator has been appraised by metallographic examination of representative specimens of each of the 12 different superalloys and 20 different superalloy-coating systems from the base-line test and the test with 0.1 per cent by volume of Ethyl CI-2 added to the fuel, using the procedure described in Appendix 3, Section 10.3, of this report. A total of 144 specimens were subjected to metallographic examination, and over 400 photomicrographs were taken of cross-section coupons to show the condition of the corrosion interface on these specimens. It is felt that the 62 photomicrographs selected for presentation in this report, and shown in the composite Figures 26 through 47, illustrate with fair accuracy the mode by which the aggressive-thermal environment deteriorated the protective coatings and the nature of the corrosive attack experienced by the various superalloys under the conditions of this investigation.

Cross-section coupons from one specimen of each material tested during this investigation were examined in the as-received condition. The surface and matrix of the 12 different superalloys were found to be free from any unusual scale or impurities, and when etched their surfaces showed no evidence of alloy depletion. The aluminum-rich coating (Misco MDC-1) which had been applied only to the nickel-base alloys appeared to be very uniform, and our best estimates of coating thickness were within ±0.1 mils of the certified values shown in Table 46 (Appendix 2, Section 9.1). As detailed in Appendix 3, Section 10.3, of this report, considerable difficulty was encountered in measuring the thickness of the aluminum-chromium-rich coating (Misco MDC-9); however, our best estimates of coating thickness were within ±0.3 mil of the mean (2.9 mils) for all of the superalloys, which indicates greater uniformity than the certified values shown in Table 46. Thus, our metallographic examination indicated that test specimens of the 12 different superalloys and 20 different superalloy-coating systems were suitable for use in this investigation. For purpose of illustration, photomicrographs (500X magnificantion) of a cross-section coupon from a low-chromium superalloy (Mar M-246), and from its coating systems (Misco MDC-1 and Misco MDC-9), in the as-received condition are shown in Figure 26. Similarly, photomicrographs of a high-chromium nickel-base superalloy (IN-738) and a cobalt-base superalloy (X-40) are shown in Figures 34 and 42, respectively.

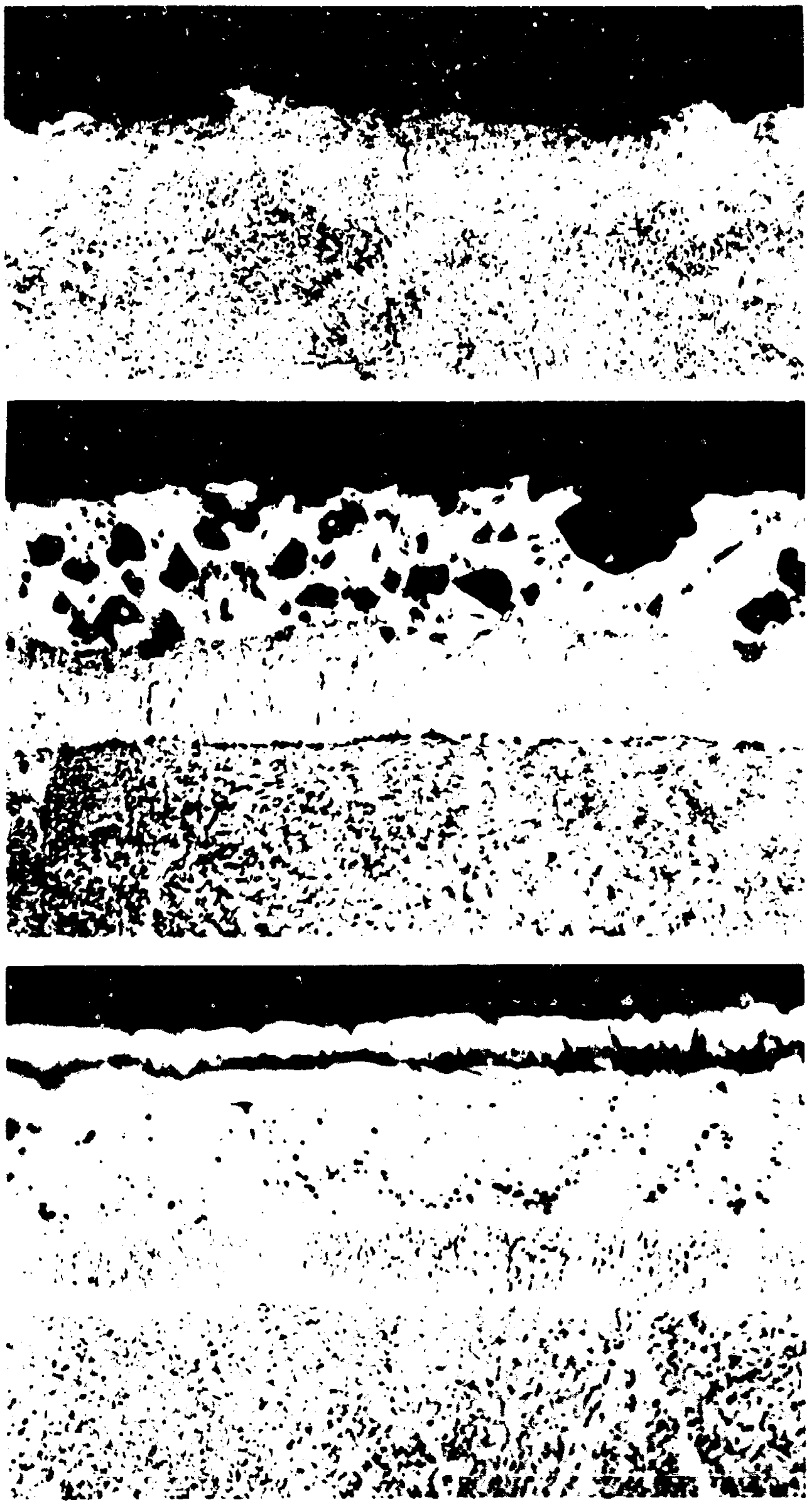
The micro-features of hot corrosion, which have been described already, were evident on the bare specimens of all 12 different superalloys following their exposure in the Turbine Simulator during this investigation. It is pertinent to note that the extent of subsurface deterioration was only about one mil on the superalloys that had the least resistance to hot corrosion, as illustrated in Figures 27 by the photomacrograph (9X magnification) and in Figure 28 by the photomicrographs (100X, 500X, and 2,000X magnification) of a cross-section coupon from a Mar M-246 specimen after 15 hours exposure. The layer of partially oxidized metal increased to a depth of near near 10 mils on the more resistant superalloys, which required much longer

exposure to reach superficially comparable levels of destruction. This is illustrated in Figures 35 and 36 for a nickel-base alloy (IN-738 after 40 hours) and in Figures 43 and 44 for a cobalt-base alloy (X-40 after 85 hours). It is assumed that this results from more-rapid oxidation of the depleted surface layer with lower-chromium-content superalloys.

At the exposure times for incipient failure, coating breakdown was not completely uniform over the entire surface of the specimens. Where still intact, the coatings usually suffered aluminum depletion. Destruction of the outer-layer was usually evidenced by oxide penetration; however, it is of interest to note that the attack on the diffusion-zone was frequently led by sulfide penetration. Once the coating was penetrated, the mode and intensity of attack observed was similar to that on the bare superalloys. This is illustrated in Figures 30 (Misco MDC-1 coated Mar M-246 after 80 hours) and 38 (Misco MDC-1 coated IN-738 after 95 hours) for the aluminum-rich coating on a low- and a high-chromium superalloy. Similarly, this is illustrated in Figures 32 (Misco MDC-9 coated Mar M-246 after 110 hours), 40 (Misco MDC-9 coated IN-738 after 165 hours), and 46 (Misco MDC-9 coated X-40 after 70 hours) for the aluminum-chromium-rich coating on a low- and a high-chromium nickel-base superalloy as well as a cobalt-base alloy. Thus, our metallographic examination indicated little difference between the 20 different superalloy-coating systems in their mode of failure until after coating breakdown and substantial penetration of the base alloys.

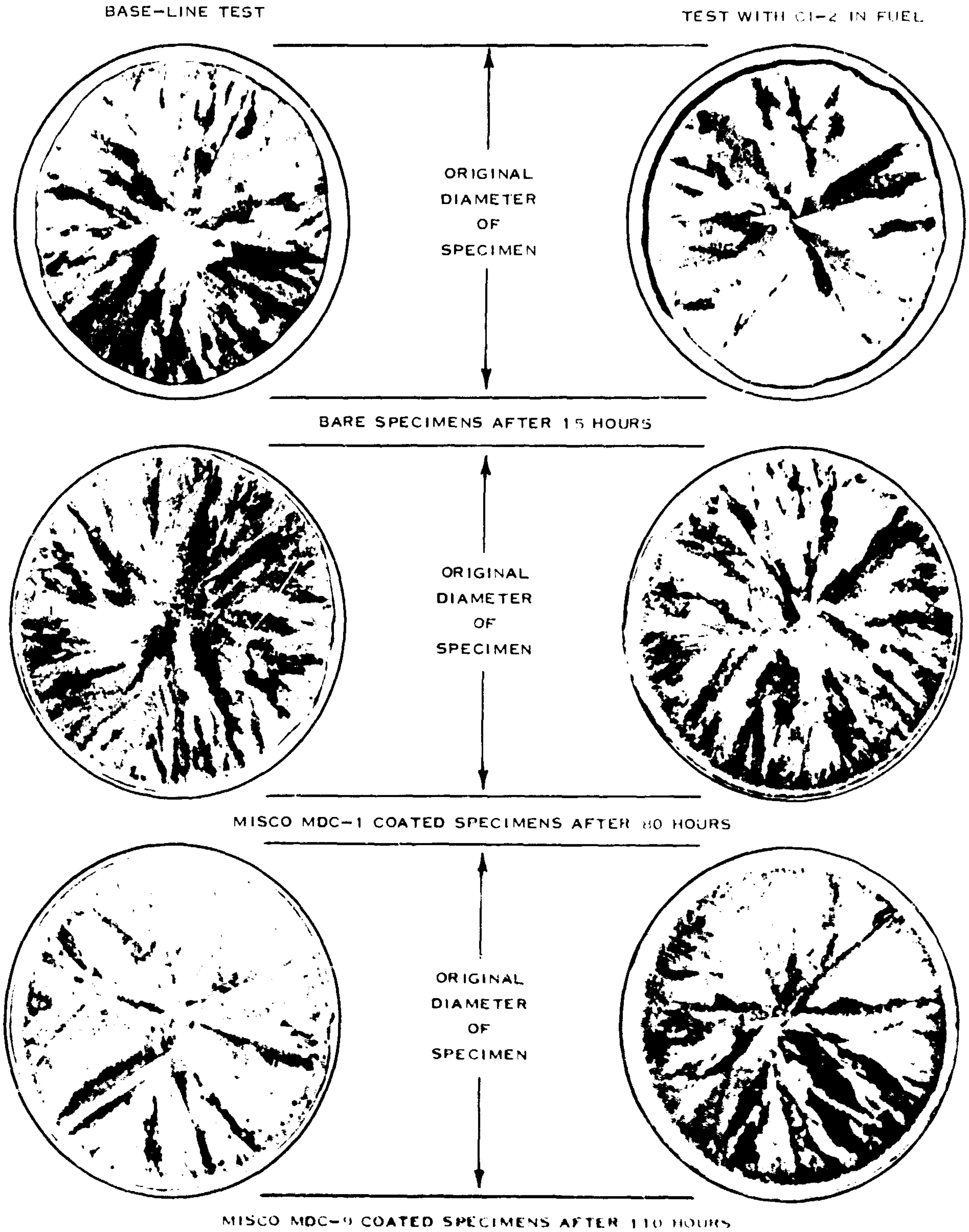
Comparable specimens from the test with 0.1 per cent by volume of Ethyl CI-2 added to the fuel show a somewhat greater surface roughness; i.e., areas with pits where grains have been lost from the alloy surface or have been isolated by oxide penetration. However, there is little or no evidence of unusual or localized penetration of the matrix of the alloy by corrosion products. This is illustrated for a low-chromium superalloy (Mar M-246), and its coating systems, by the photomicrographs (9X magnification) shown in Figure 27 and the photomicrographs (100X, 500X, and 2,000 X magnification) shown in Figures 29, 31 and 32. Similarly, comparisons can be made for a high-chromium nickel-base superalloy (IN-738) using Figures 35, 37, 39 and 41, and for a cobalt-base alloy (X-40) using Figures 43, 45, and 47.

In general, metallographic examination of representative specimens following exposure, and after electro-cleaning to remove surface scale, showed that subsurface attack on the low-chromium superalloys and their coating systems was limited to shallow penetration by corrosion products (about one mil), despite catastrophic rates of metal loss; however, subsurface deterioration to depths approaching 10 mils was evident on the more resistant high-chromium superalloys and their coating systems. There was somewhat greater surface roughness evidenced on specimens exposed during the test with the manganese additive; however, this was not accompanied by obvious changes in the depth of subsurface penetration by corrosion products. Since the extent of subsurface attack on the high-chromium superalloys, and their coating systems, was found to be of sufficient magnitude to indicate that weight-loss data may not reflect the extent of total metal damage to specimens, it was decided that evaluation of metal damage should be made by both the weight-loss method and the penetration method to facilitate comparisons for determining whether hot corrosion was increased by use of the manganese additive during this investigation.



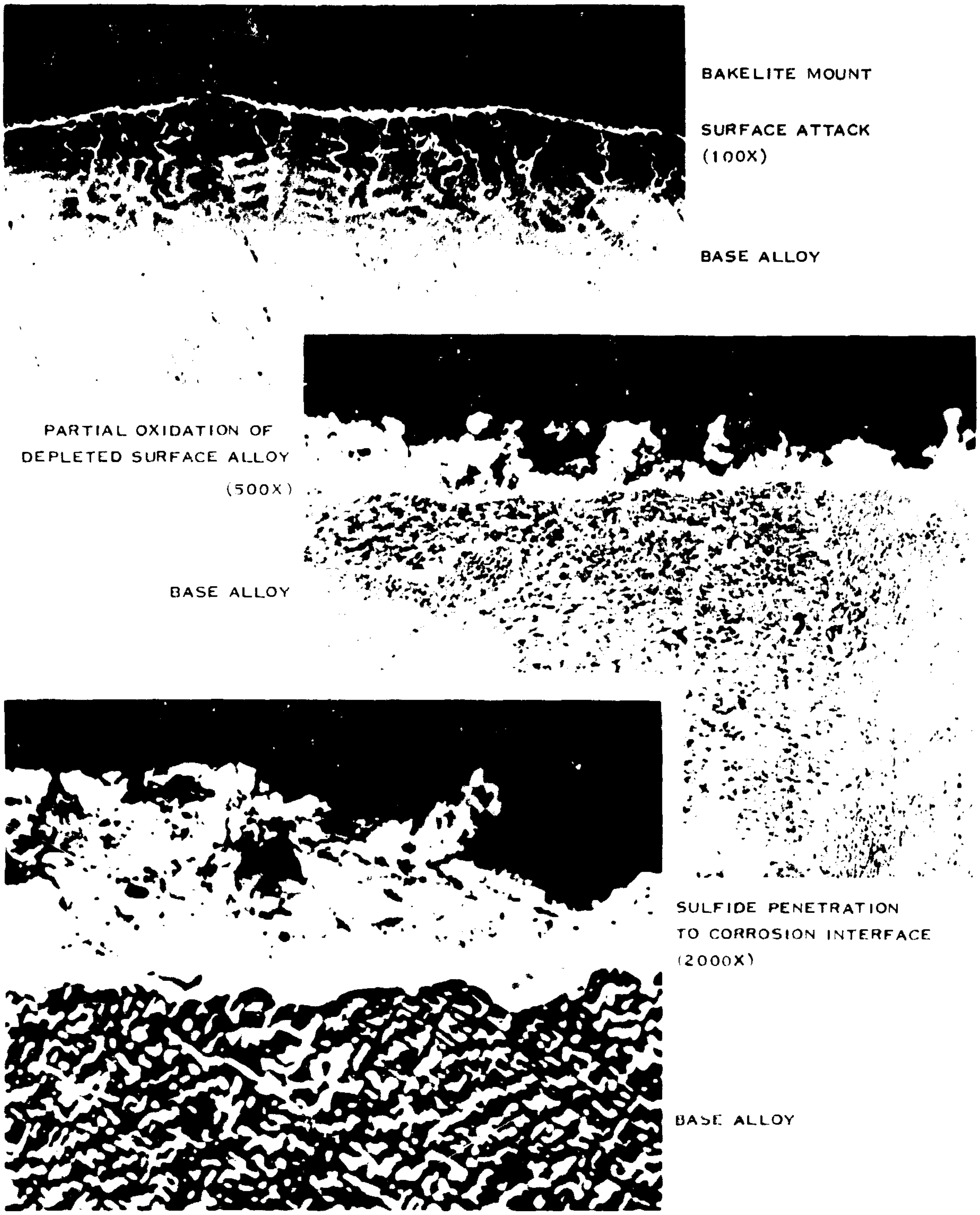
METALLOGRAPHIC CROSS-SECTION OF SPECIMENS
10% OXALIC ACID-ELECTROLYTIC ETCHED.
500X MAGNIFICATION.

FIGURE 26
REPRESENTATIVE MM 246 SPECIMENS AS-RECEIVED UNEXPOSED



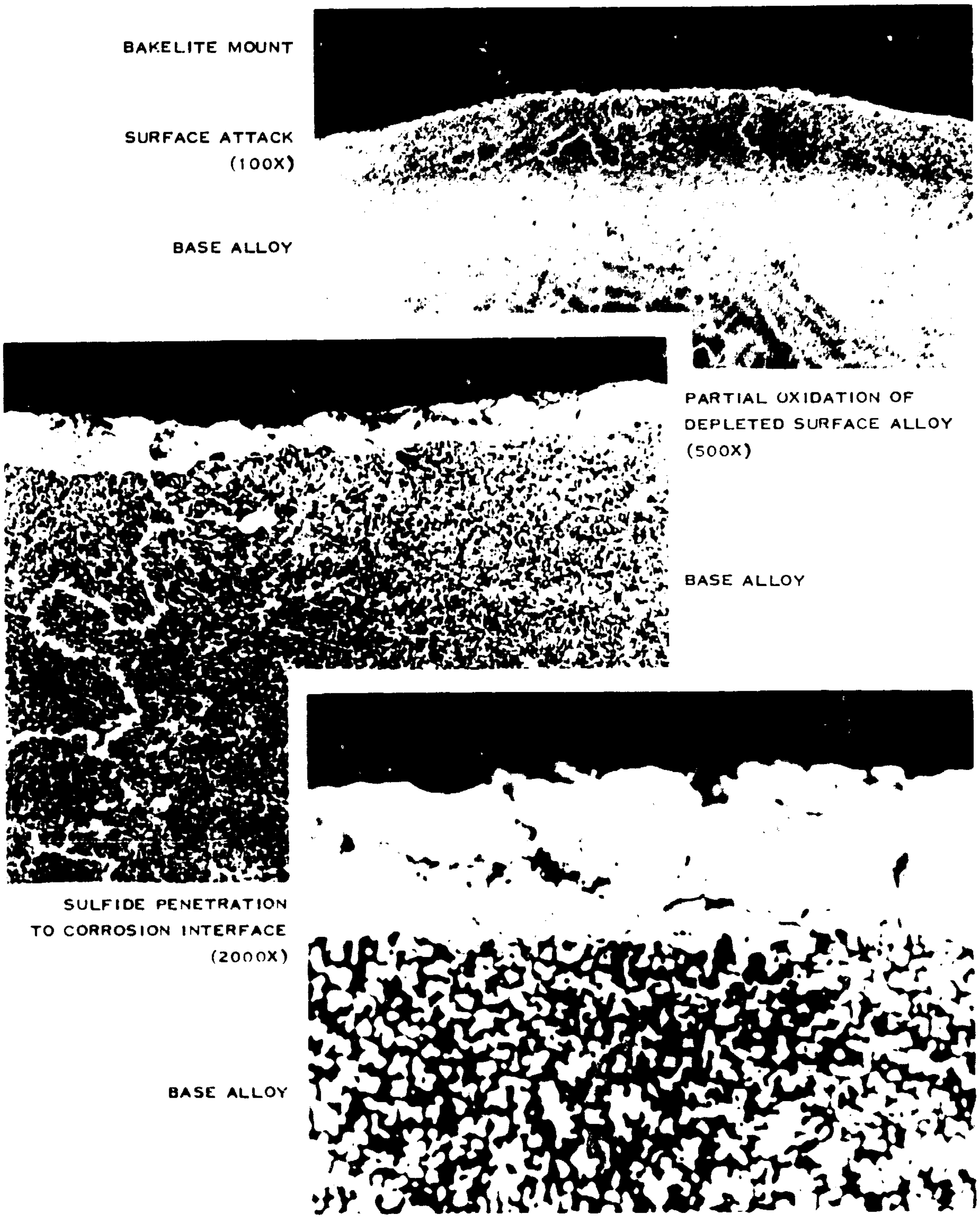
METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL, ELECTRO-CLEANED, 10% OXALIC ACID-ELECTROLYTIC ETCHED, [illegible]X MAGNIFICATION.

FIGURE 27
HOT CORROSION OF MM 246 SPECIMENS



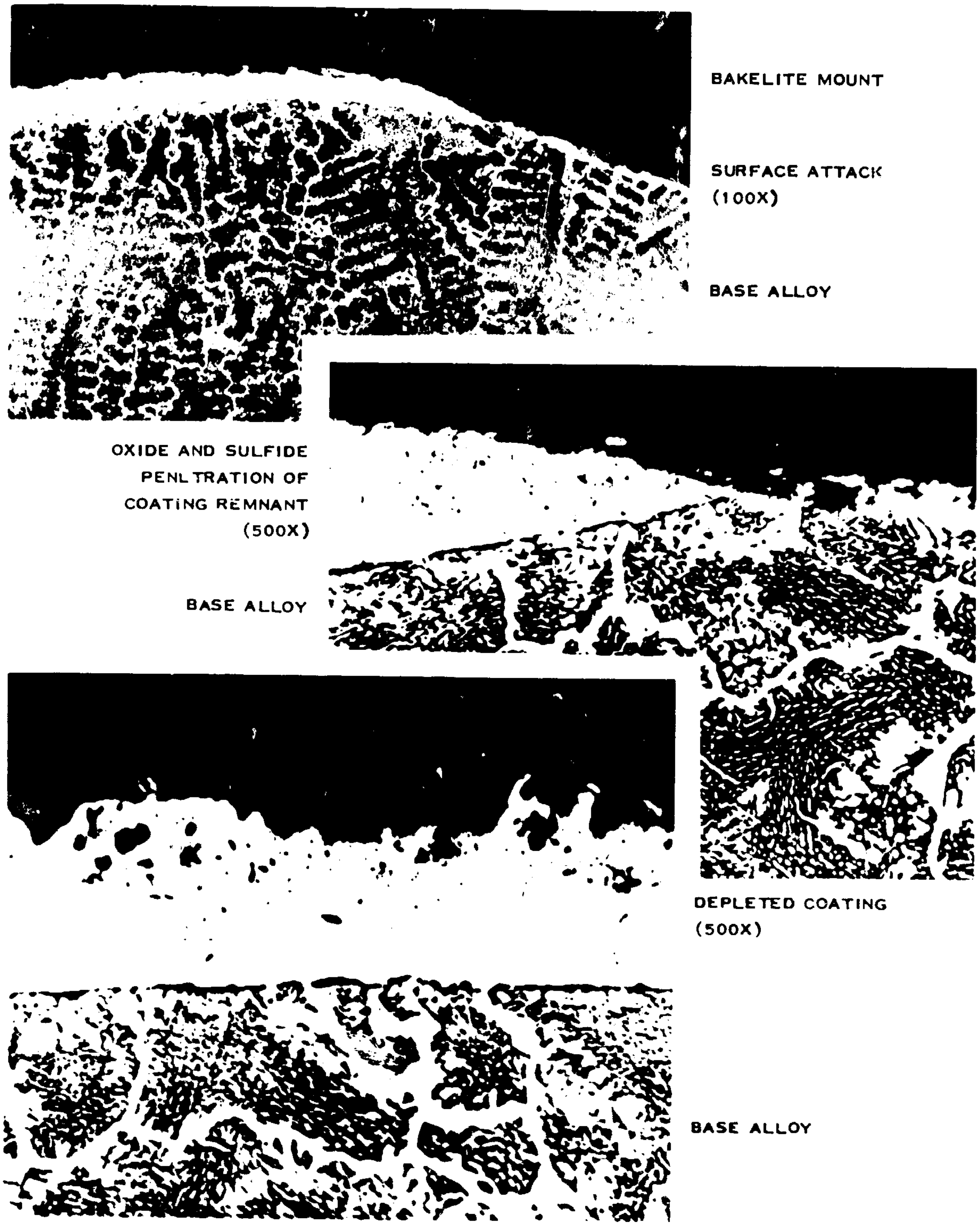
METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL, ELECTRO-CLEANED, 10% OXALIC ACID-ELECTROLYTIC ETCHED.

FIGURE 28
HOT CORROSION OF BARE MM-246 SPECIMEN AFTER 15 HOURS
(BASE-LINE TEST)



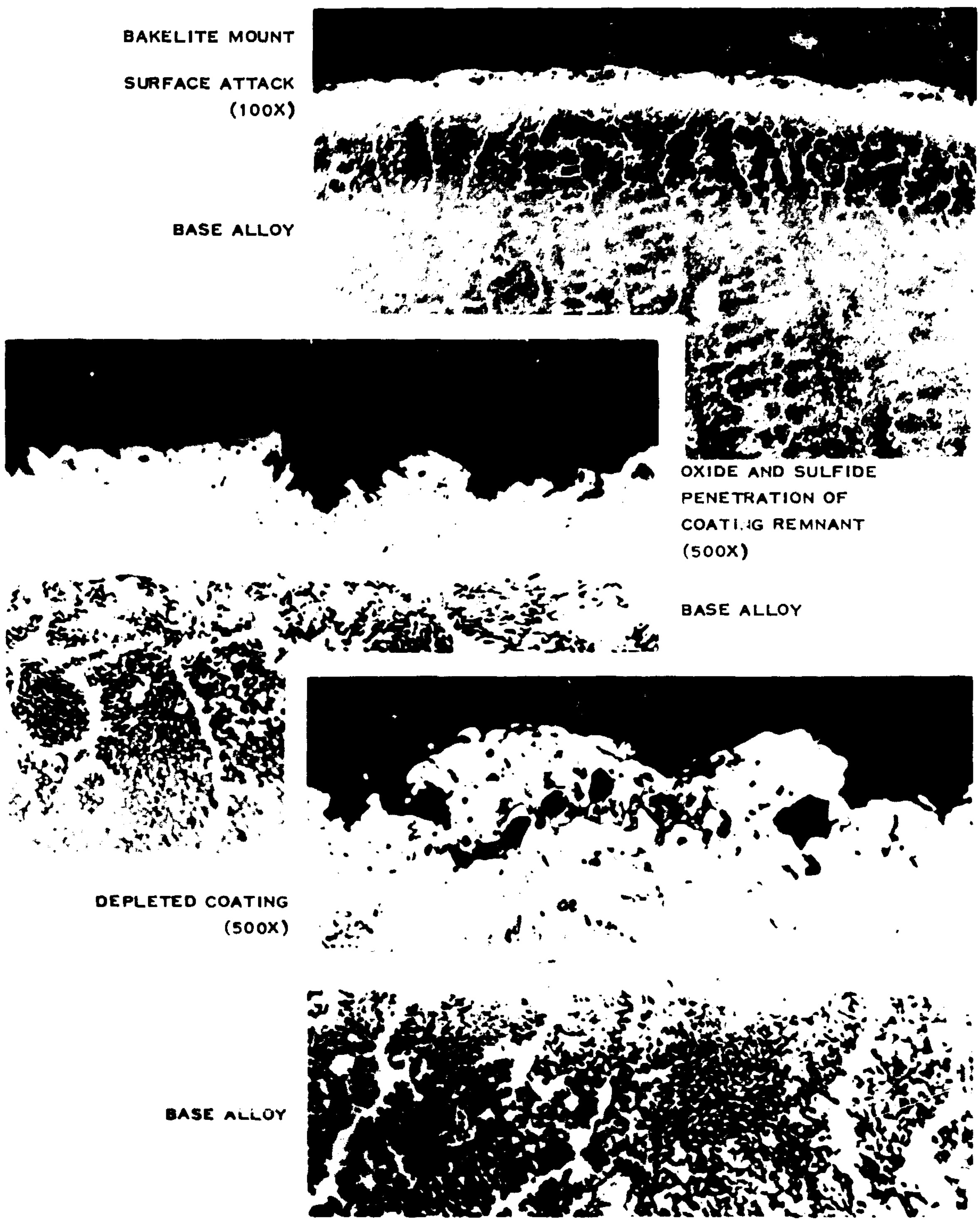
METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL PLUS 0.1 VOL % ETHYL CI-2 ADDED TO FUEL.
ELECTRO-CLEANED, 10% OXALIC ACID-ELECTROLYTIC ETCHED.

FIGURE 29
HOT CORROSION OF BASE MM-246 SPECIMEN AFTER 15 HOURS
(TEST WITH CI-2 IN FUEL)



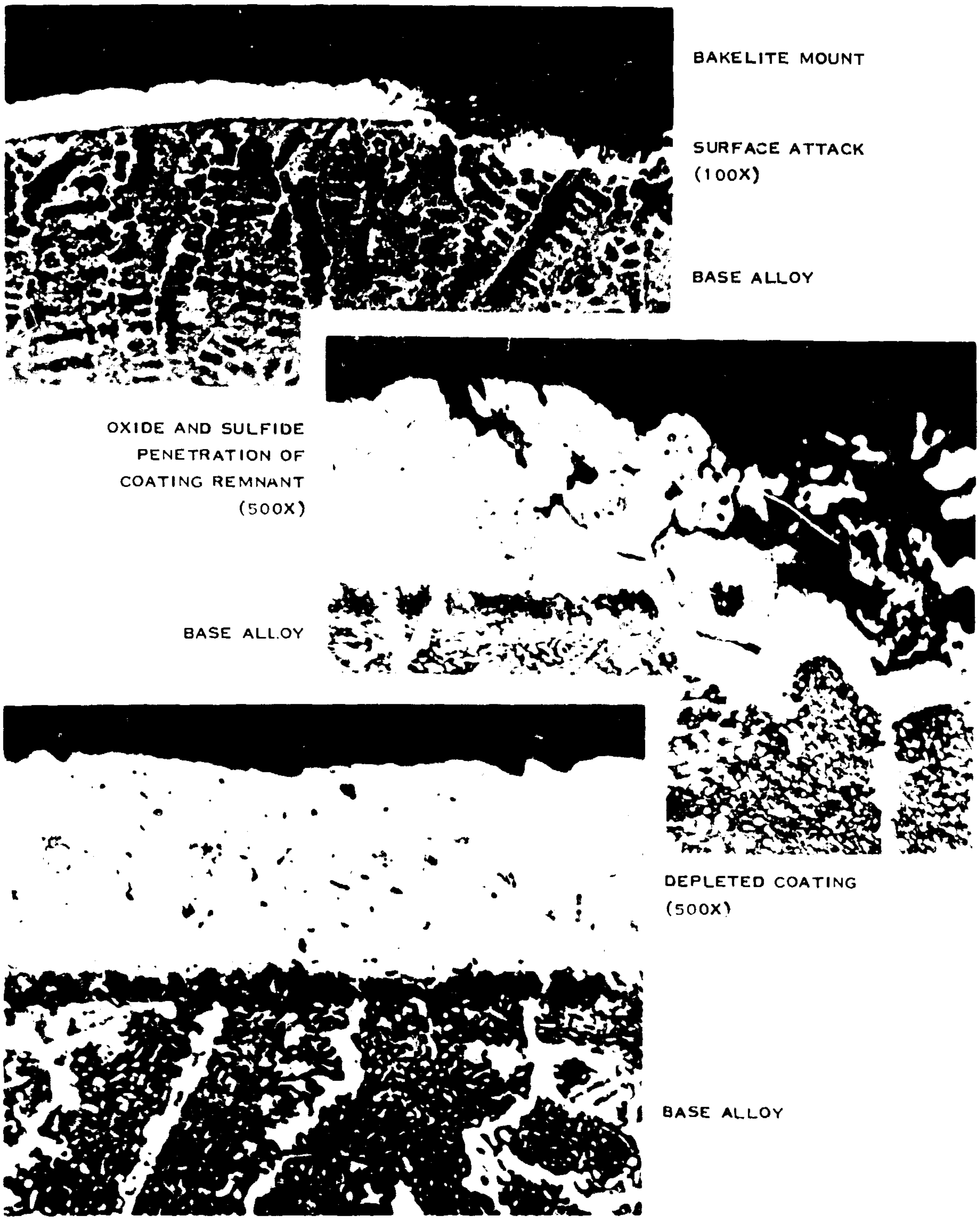
METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL. ELECTRO-CLEANED. 10% OXALIC ACID-ELECTROLYTIC ETCHED.

FIGURE 30
HOT CORROSION OF MISCO MDC-1 COATED MM-246 SPECIMEN AFTER 80 HOURS
(BASE-LINE TEST)



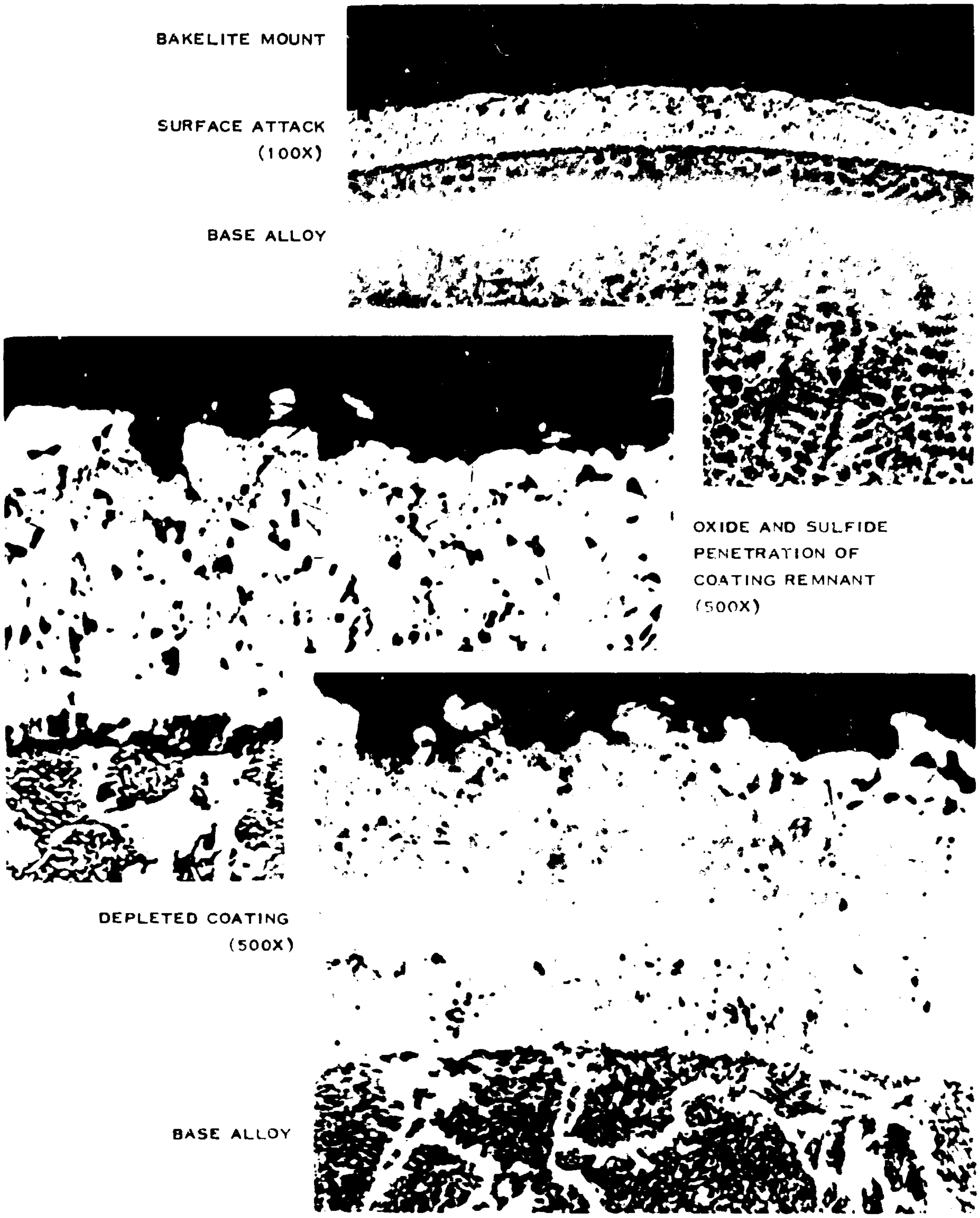
METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL PLUS 0.1 VOL % ETHYL CI-2 ADDED TO FUEL.
ELECTRO-CLEANED. 10% OXALIC ACID-ELECTROLYTIC ETCHED.

FIGURE 31
HOT CORROSION OF MIDCO MDC-1 COATED MM-246 SPECIMEN AFTER 80 HOURS
(TEST WITH CI-2 IN FUEL)



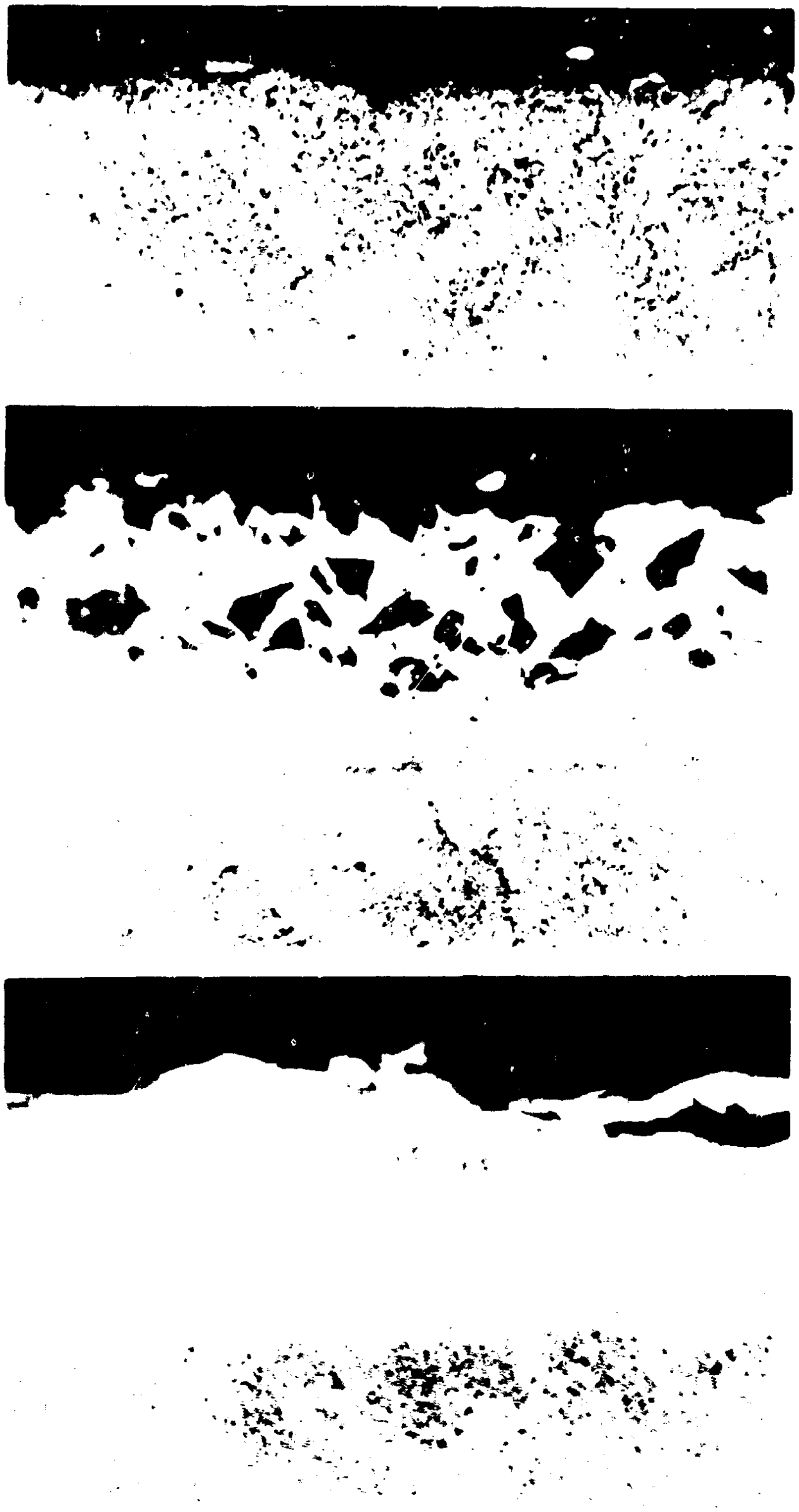
METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL. ELECTRO-CLEANED. 10% OXALIC ACID-ELECTROLYTIC ETCHED.

FIGURE 32
HOT CORROSION OF MISCO MDC-9 COATED MM-246 SPECIMEN
AFTER 110 HOURS (BASE-LINE TEST)



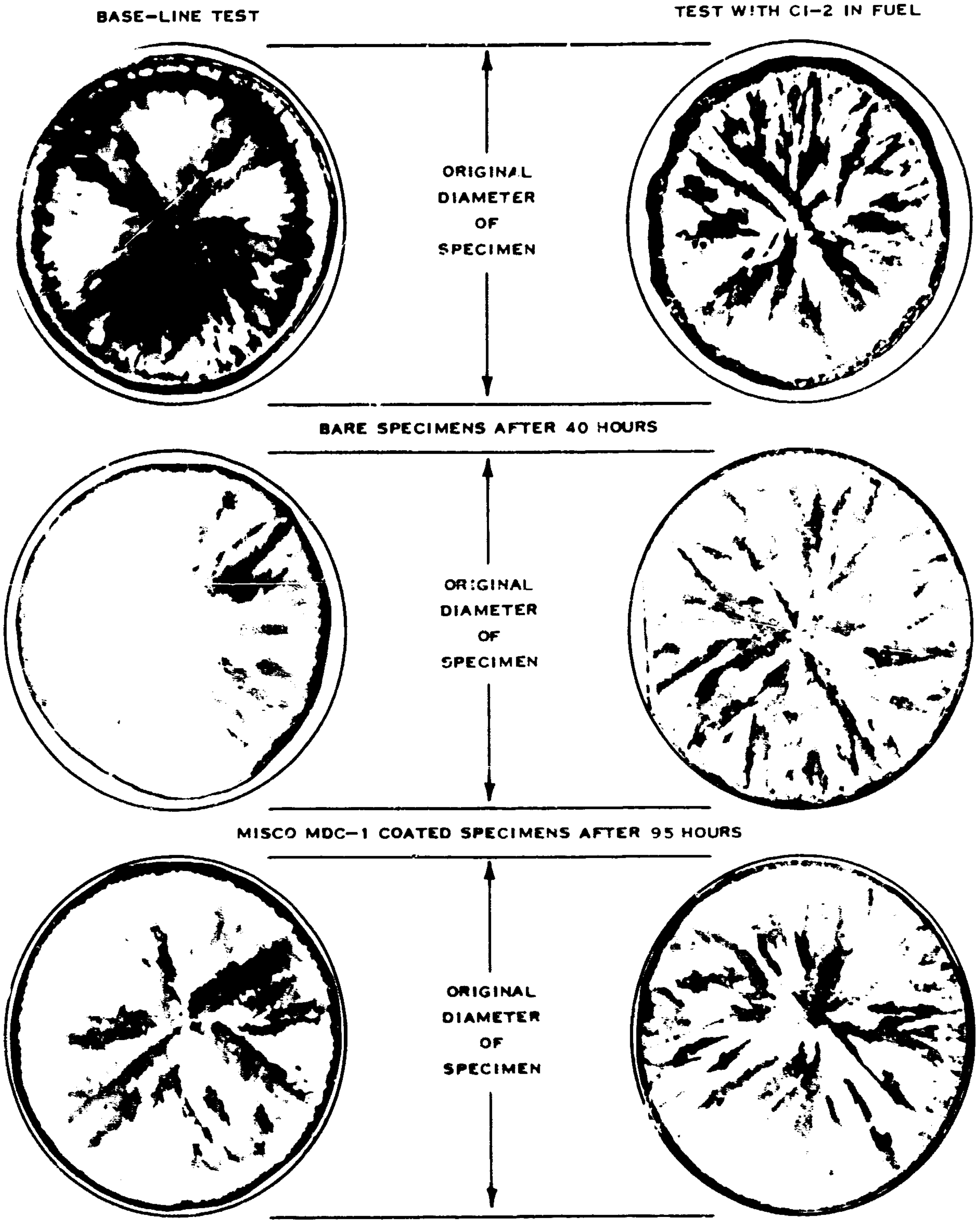
METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL PLUS 0.1 VOL % ETHYL CI-2 ADDED TO FUEL.
ELECTRO-CLEANED. 10% OXALIC ACID-ELECTROLYTIC ETCHED.

FIGURE 33
HOT CORROSION OF MISCO MDC-9 COATED MM-246 SPECIMEN AFTER 110 HOURS (TEST WITH CI-2 IN FUEL)



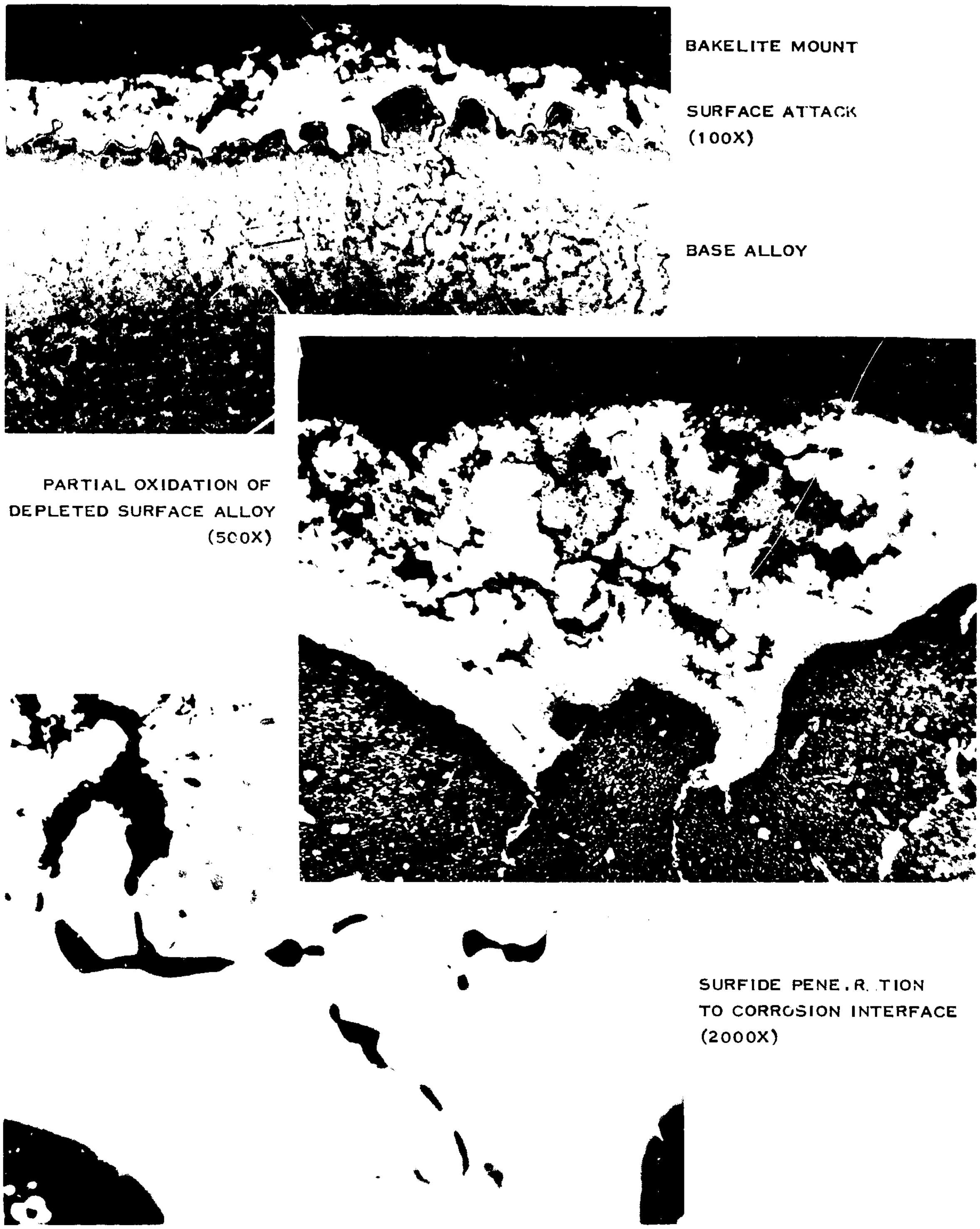
METALLOGRAPHIC CROSS-SECTION OF SPECIMENS.
10% OXALIC ACID-ELECTROLYTIC ETCHED.
500X MAGNIFICATION.

FIGURE 34
REPRESENTATIVE IN-738 SPECIMENS AS-RECEIVED UNEXPOSED



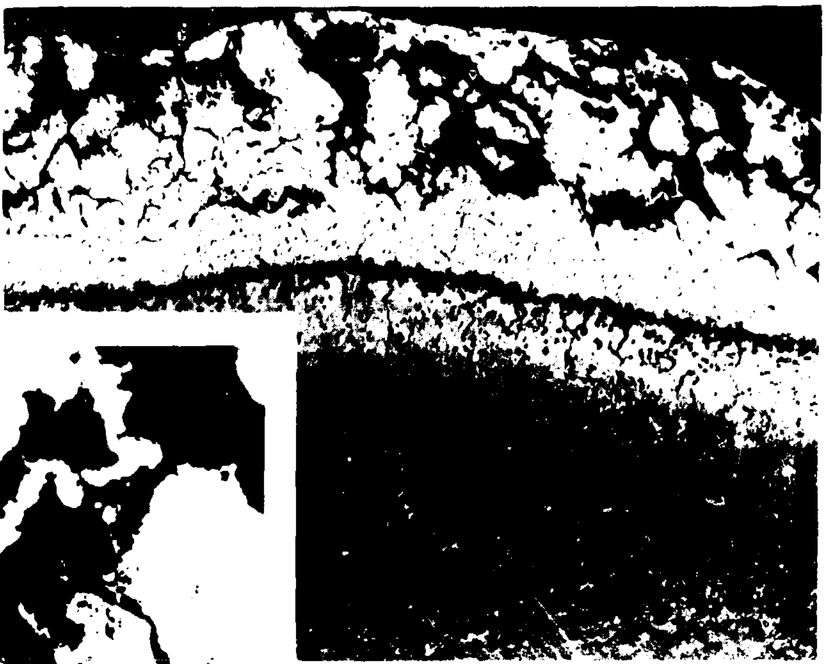
METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL. ELECTRO-CLEANED. 10% OXALIC ACID-ELECTROLYTIC ETCHED. 9X MAGNIFICATION.

FIGURE 35
HOT CORROSION OF IN-738 SPECIMENS



METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL. ELECTRO-CLEANED. 10% OXALIC ACID-ELECTROLYTIC ETCHED.

FIGURE 36
HOT CORROSION OF BARE IN-738 SPECIMEN AFTER 40 HOURS
(BASE-LINE TEST)

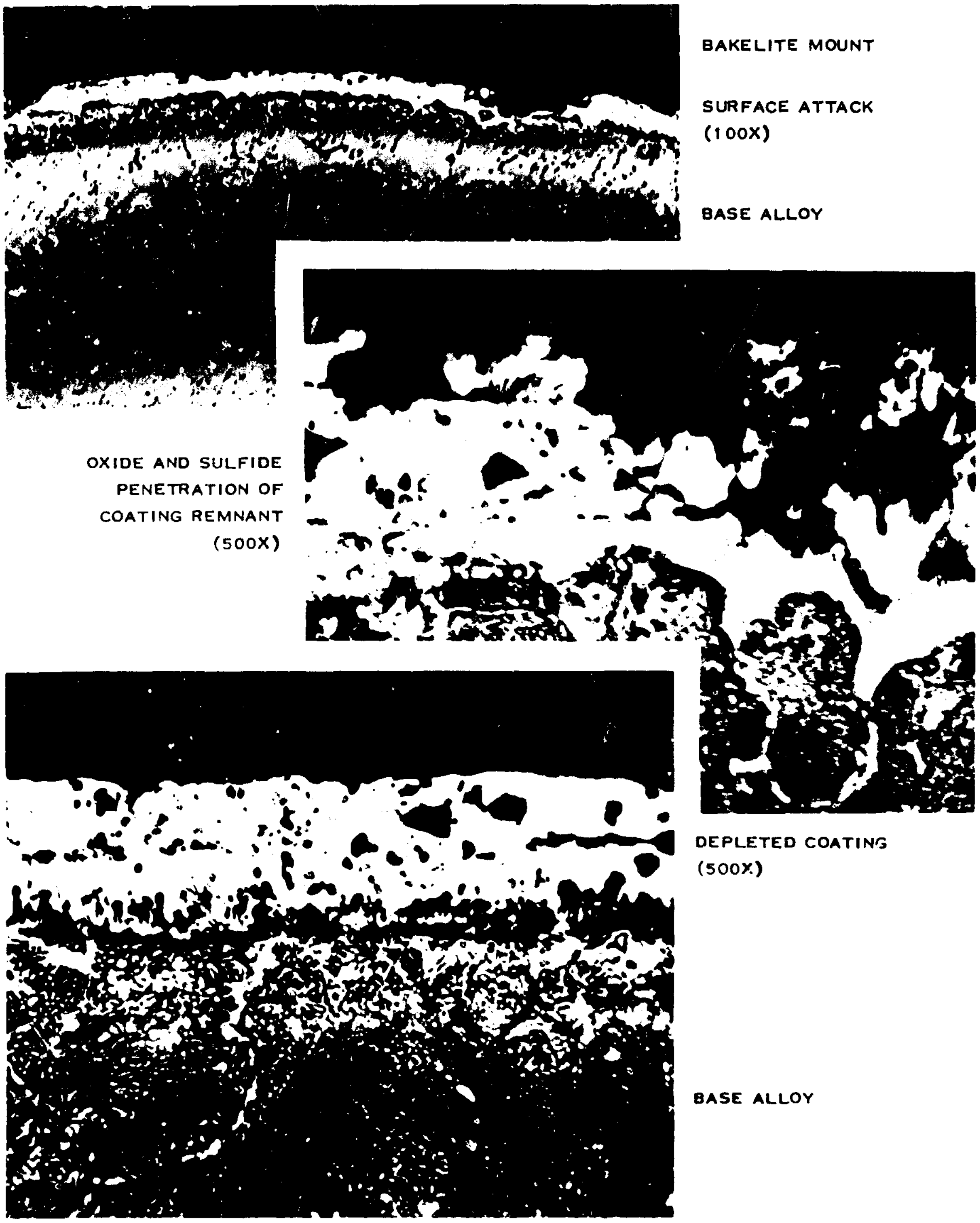


PARTIAL OXIDATION OF
DEPLETED SURFACE ALLOY
(500X)

SULFIDE PENETRATION
TO CORROSION INTERFACE
(2000X)

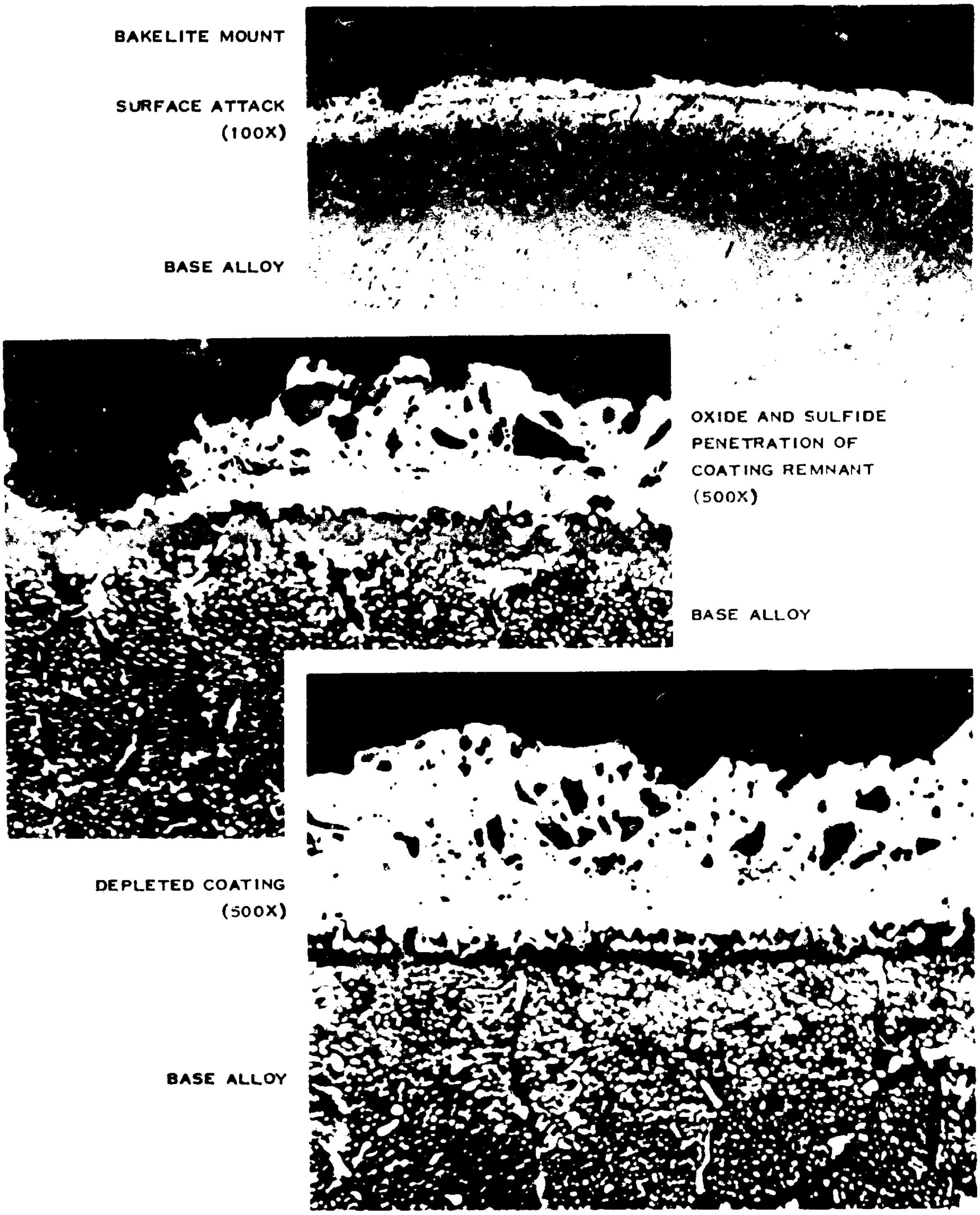
METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL. PLUS 0.1 VOL% ETHYL CI-2 ADDED TO FUEL.
ELECTRO-CLEANED. 10% OXALIC ACID-ELECTROLYTIC ETCHED.

FIGURE 37
HOT CORROSION OF BARE IN-738 SPECIMEN AFTER 40 HOURS
(TEST WITH CI-2 IN FUEL)



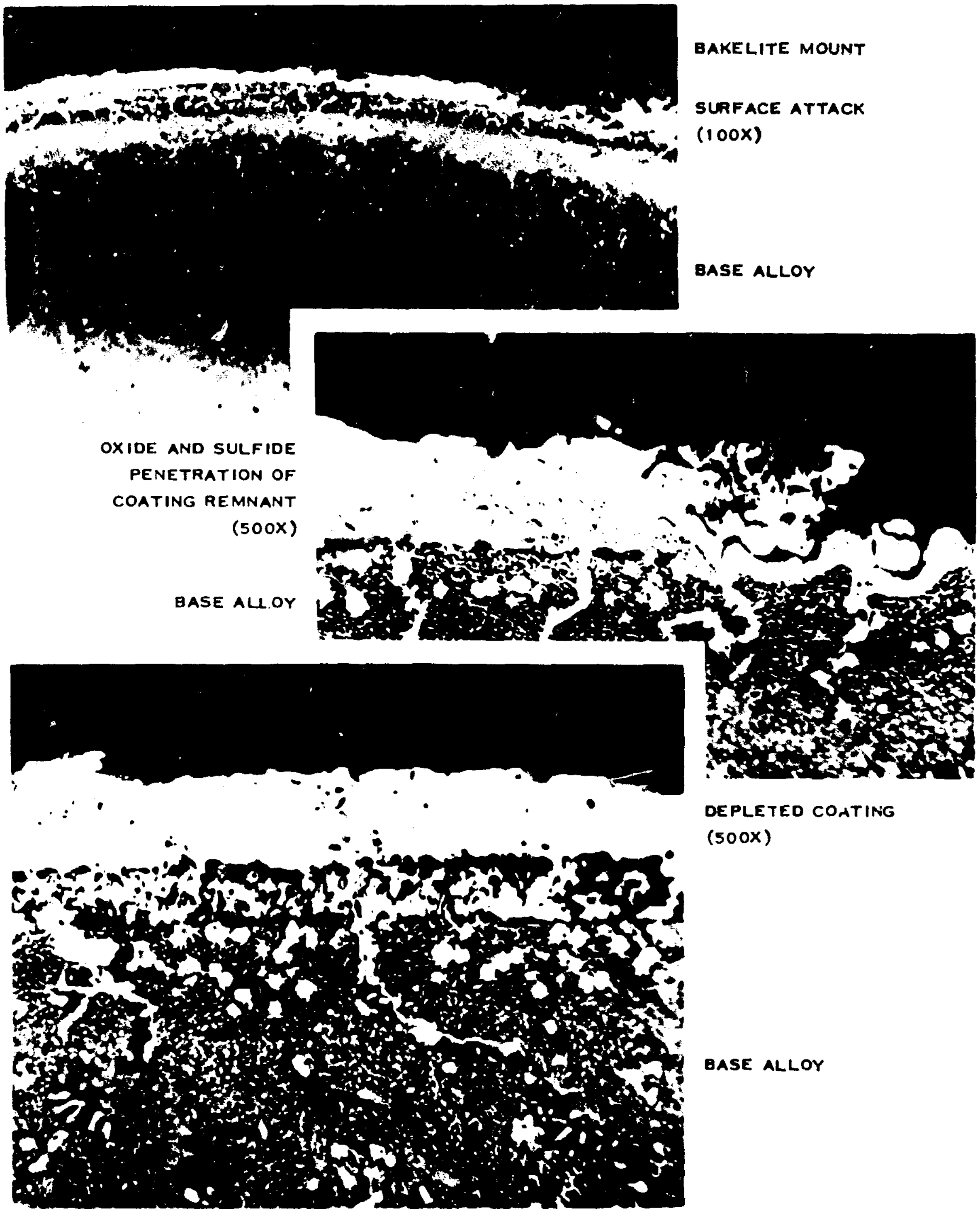
METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL. ELECTRO-CLEANED. 10% OXALIC ACID-ELECTROLYTIC ETCHED.

FIGURE 38
HOT CORROSION OF MISCO MDC-1 COATED IN-738 SPECIMEN AFTER 95 HOURS
(BASE-LINE TEST)



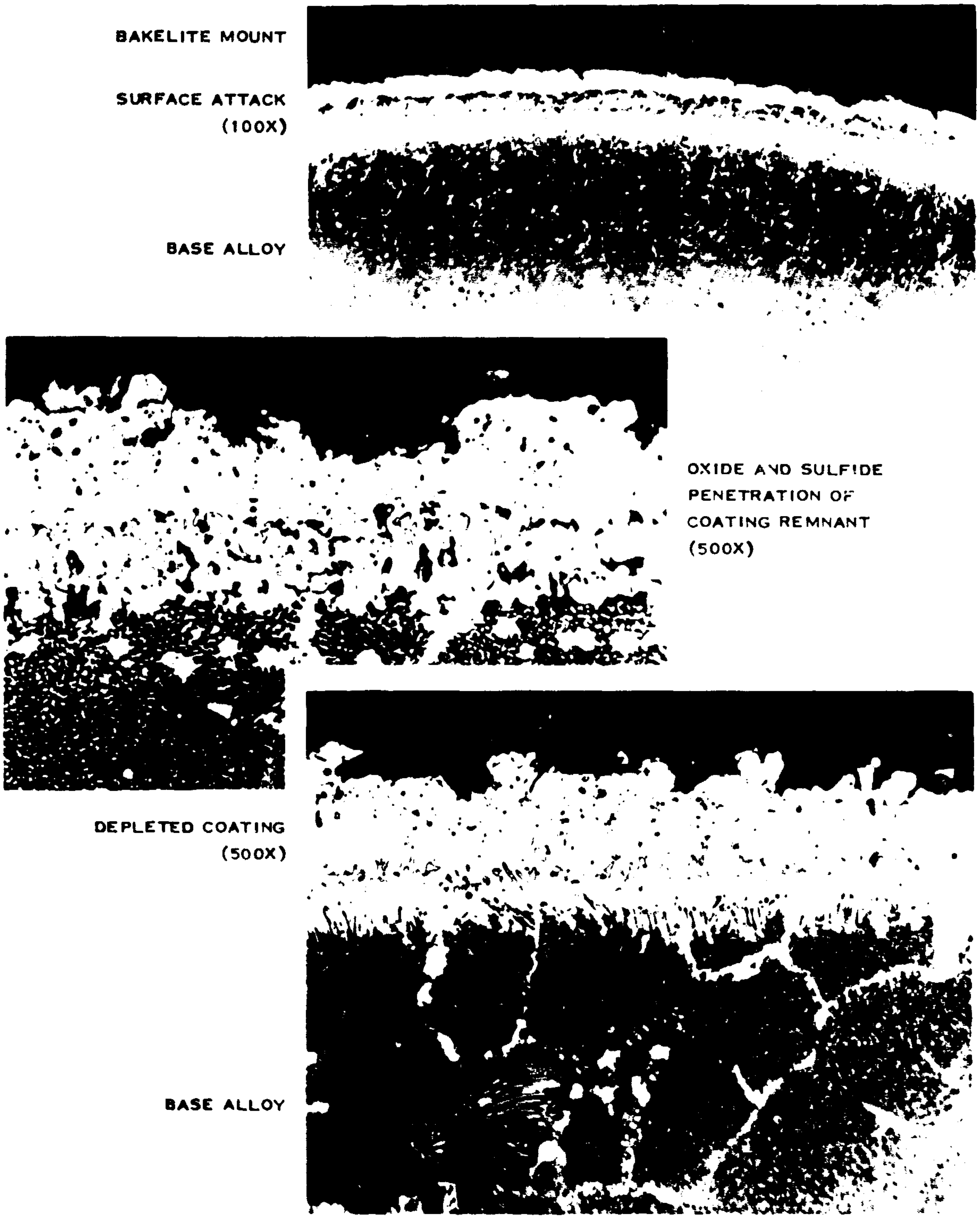
METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL PLUS 0.1 VOL % ETHYL CI-2 ADDED TO FUEL.
ELECTRO-CLEANED. 10% OXALIC ACID-ELECTROLYTIC ETCHED.

FIGURE 39
HOT CORROSION OF MISCO MDC-1 COATED IN-738 SPECIMEN AFTER 95 HOURS
(TEST WITH CI-2 IN FUEL)



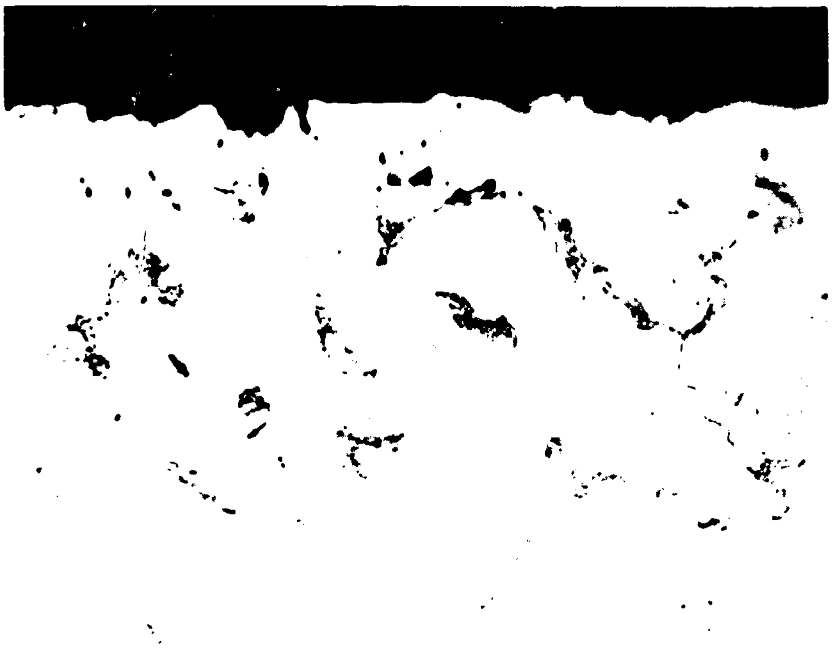
METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL. ELECTRO-CLEANED. 10% OXALIC ACID-ELECTROLYTIC ETCHED.

FIGURE 40
HOT CORROSION OF MISCO MDC-9 COATED IN-738 SPECIMEN AFTER 165 HOURS
(BASE-LINE TEST)



METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL PLUS 0.1 VOL % ETHYL CI-2 ADDED TO FUEL.
ELECTRO-CLEANED, 10% OXALIC ACID-ELECTROLYTIC ETCHED.

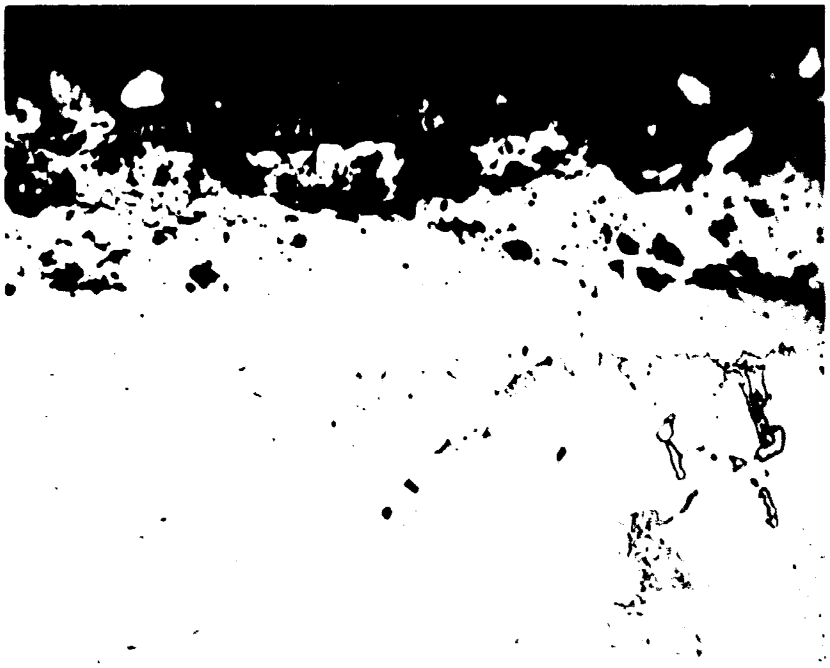
FIGURE 41
HOT CORROSION OF MISCO MDC-9 COATED IN-738 SPECIMEN AFTER 165 HOURS (TEST WITH CI-2 IN FUEL)



BAKELITE MOUNT

SURFACE OF BARE ALLOY IS CLEAN

BASE ALLOY



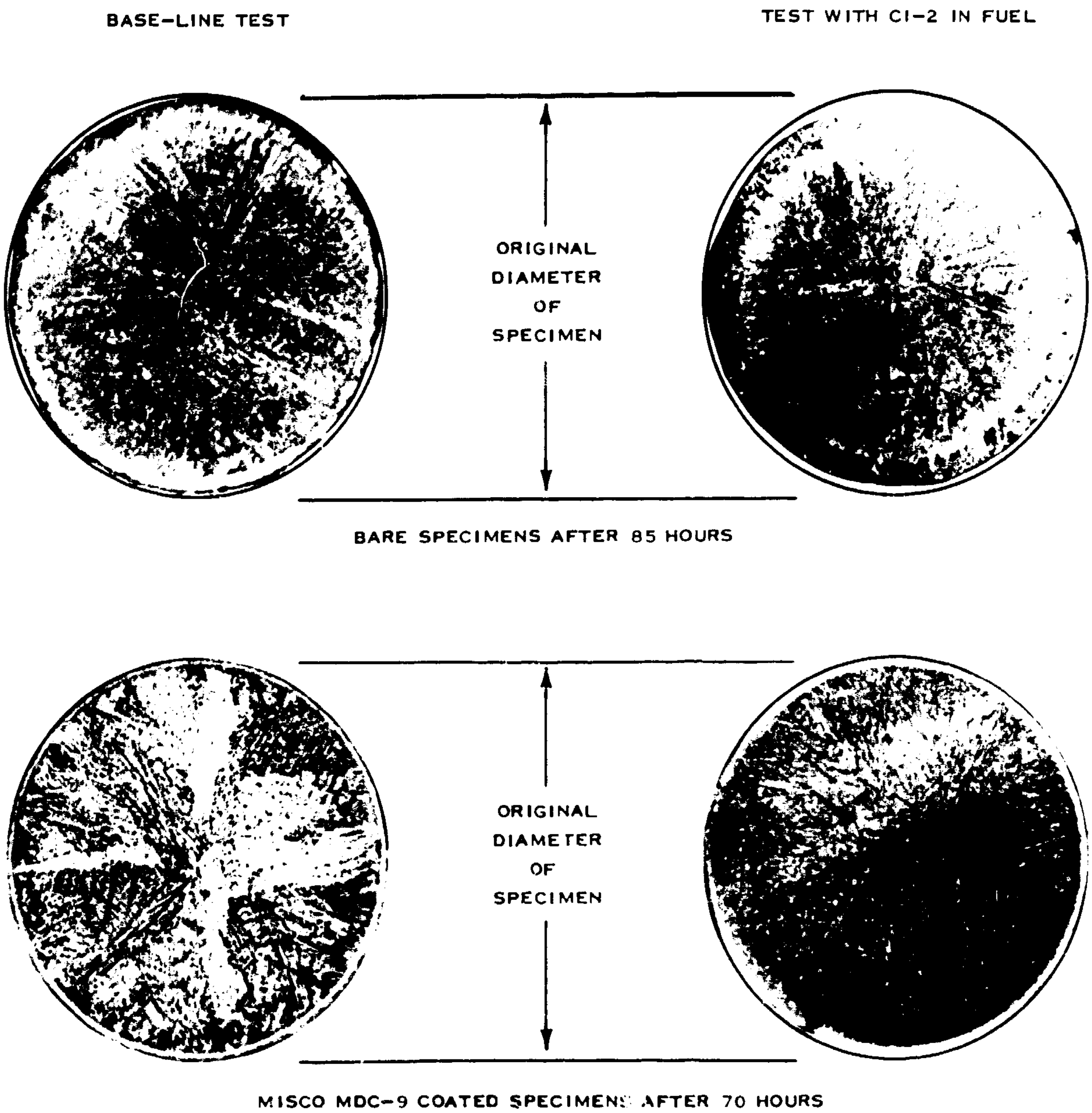
CLADDING (NICKEL)

OUTER LAYER OF MISCO MDC-9 COATING HAS POOR "GREEN" STRENGTH

BASE ALLOY

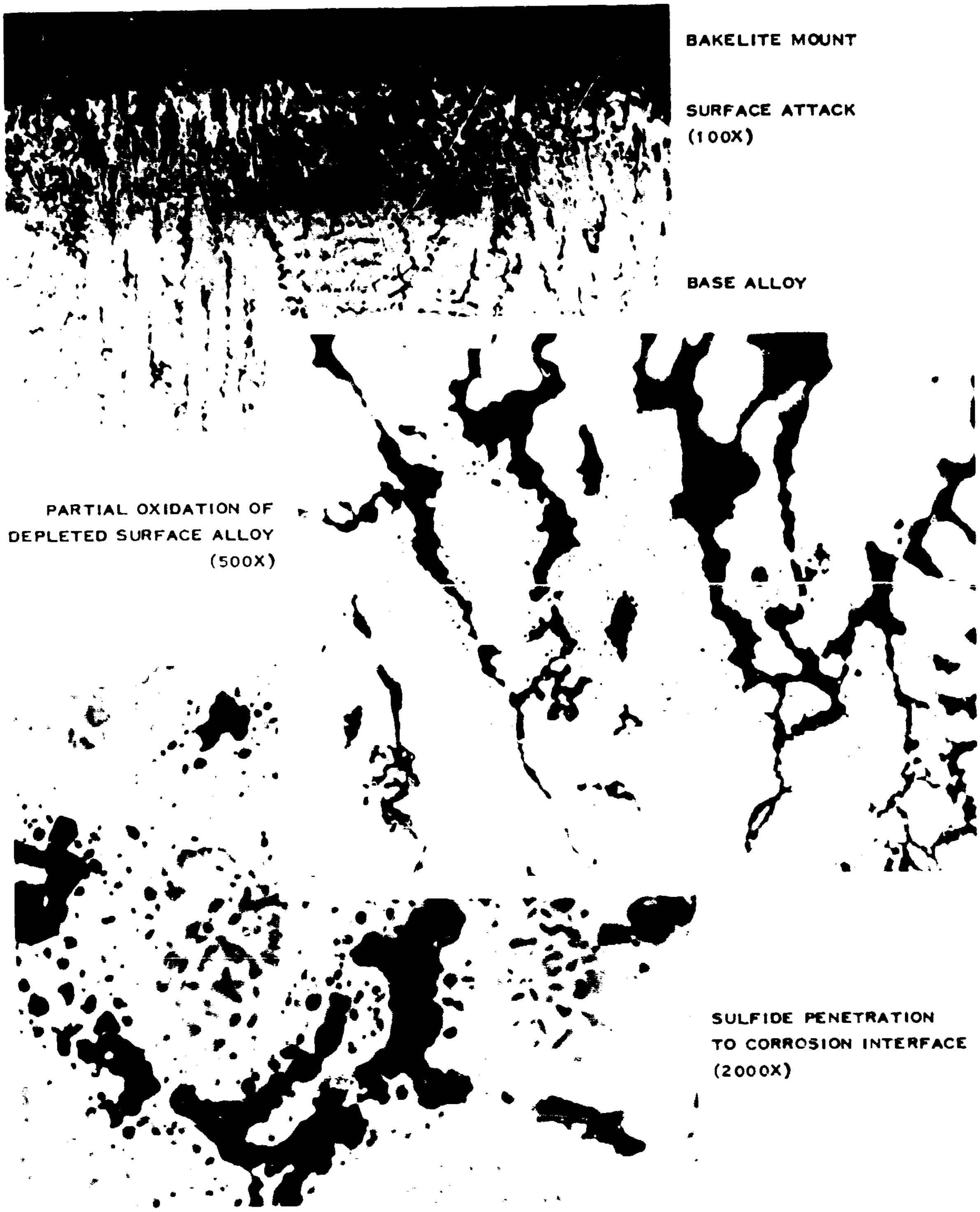
METALLOGRAPHIC CROSS-SECTION OF SPECIMENS.
MURKAMI'S REAGENT ETCHED.
500X MAGNIFICATION.

FIGURE 42
REPRESENTATIVE X-40 SPECIMENS AS-RECEIVED UNEXPOSED



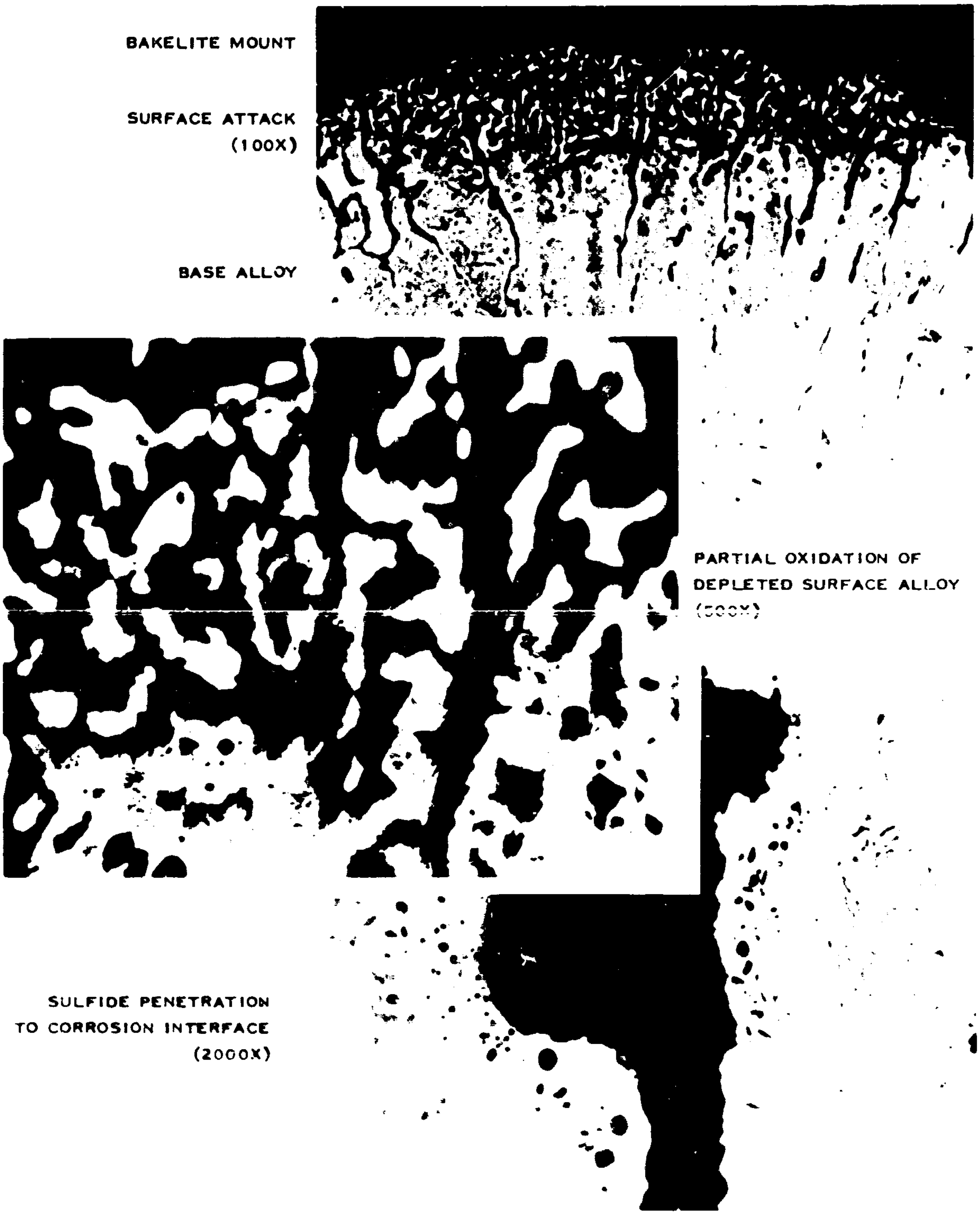
METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL. ELECTRO-CLEANED. MURKAMI'S REAGENT ETCHED. 9X MAGNIFICATION.

FIGURE 43
HOT CORROSION OF X-40 SPECIMENS



METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL. ELECTRO-CLEANED. MURKAMI'S REAGENT ETCHED.

FIGURE 44
HOT CORROSION OF BARE X-40 SPECIMEN AFTER 85 HOURS
(BASE-LINE TEST)



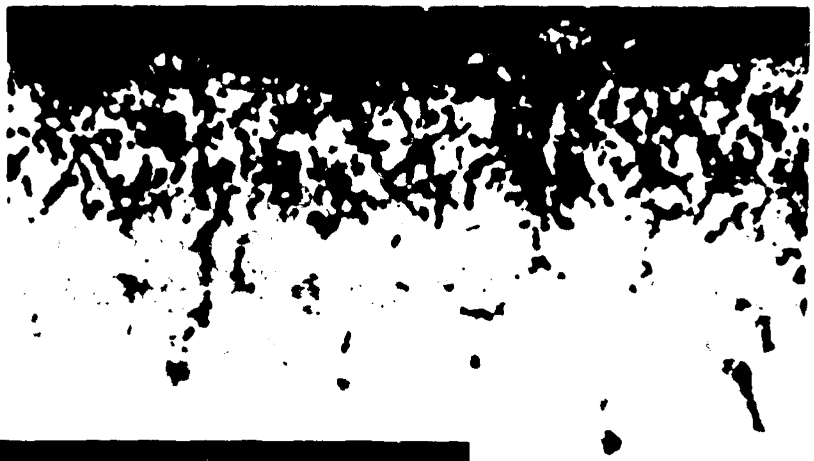
METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL PLUS 0.1 VOL % ETHYL CI-2 ADDED TO FUEL.
ELECTRO-CLEANED. MURKAMI'S REAGENT ETCHED.

FIGURE 45
HOT CORROSION OF BARE X-40 SPECIMEN AFTER 85 HOURS
(TEST WITH CI-2 IN FUEL)

BAKELITE MOUNT

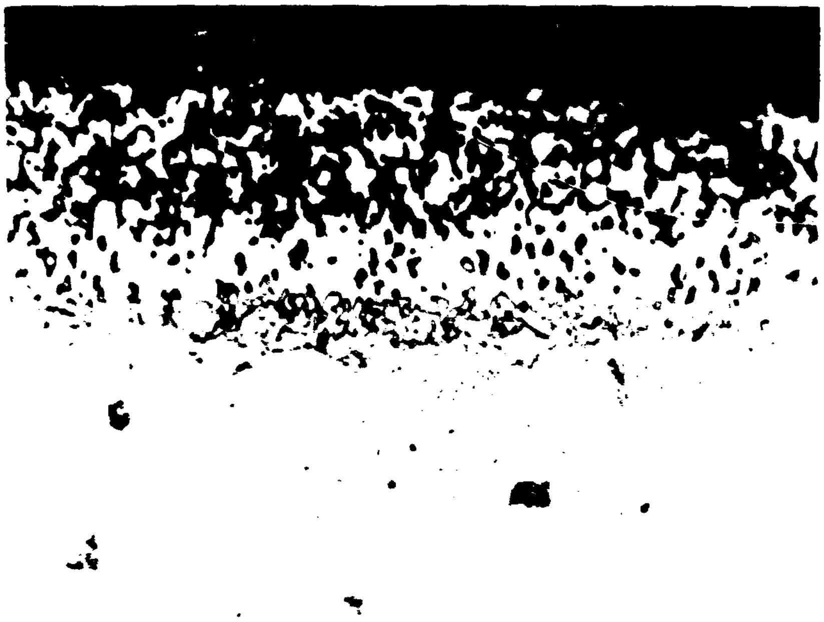
SURFACE ATTACK
(100X)

BASE ALLOY



OXIDE AND SULFIDE
PENETRATION OF
COATING REMNANT
(500X)

BASE ALLOY

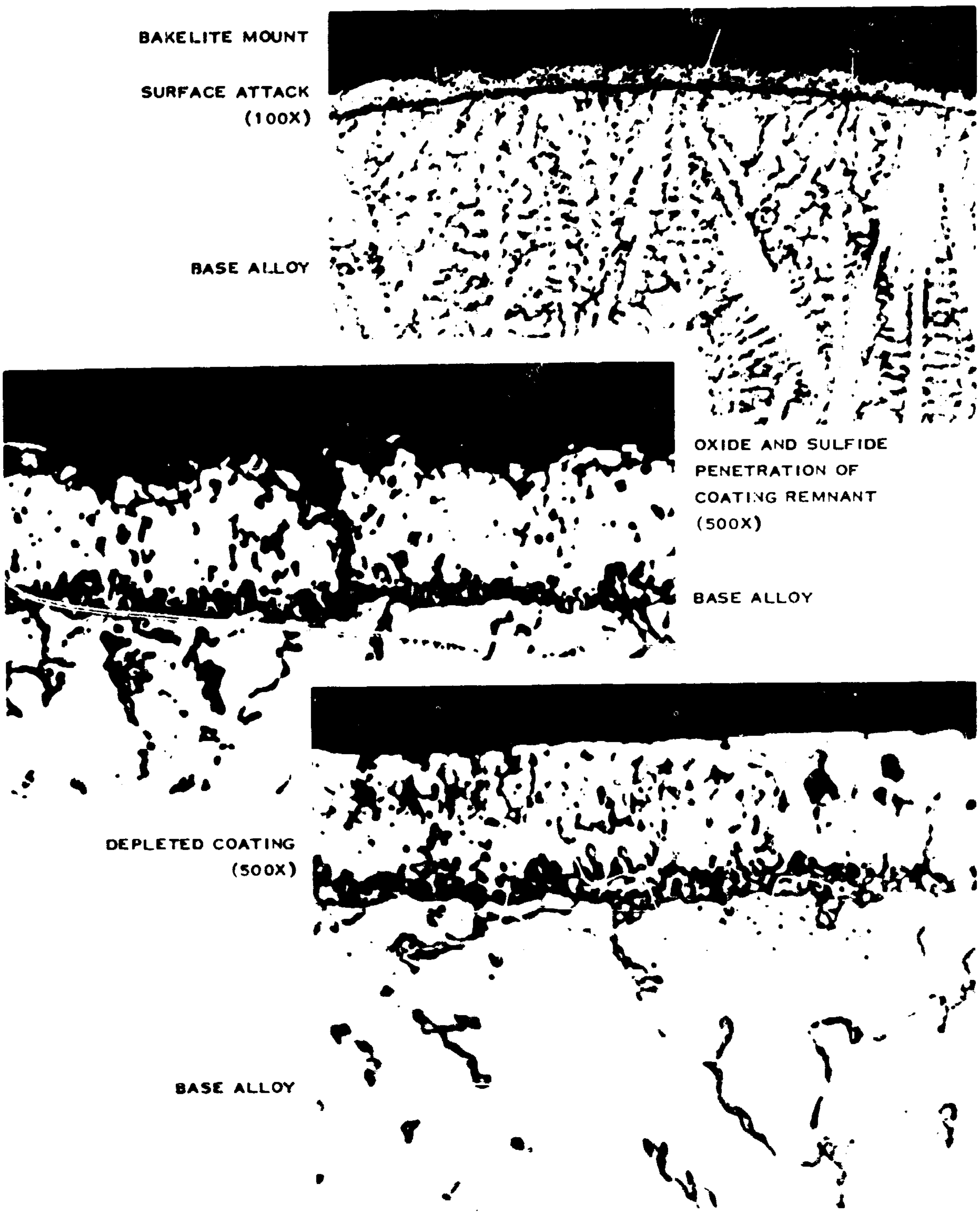


DEPLETED COATING
(500X)

BASE ALLOY

METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL. ELECTRO-CLEANED. MURAKAMI'S REAGENT ETCHED.

FIGURE 46
HOT CORROSION OF MISCO MDC-9 COATED X-40 SPECIMEN AFTER 70 HOURS
(BASE-LINE TEST)



METALLOGRAPHIC CROSS-SECTION OF SPECIMEN FROM 2000 F CYCLIC TEST IN PHILLIPS TURBINE SIMULATOR WITH 1.0 PPM SEA SALT IN AIR AND 0.04 WT % SULFUR IN FUEL PLUS 0.1 VOL % ETHYL CI-2 ADDED TO FUEL.
ELECTRO-CLEANED. MURKAMI'S REAGENT ETCHED.

FIGURE 47

HOT CORROSION OF MISCO MDC-9 COATED X-40 SPECIMEN AFTER 70 HOURS (TEST WITH CI-2 IN FUEL)

4.5. Metal-Weight-Loss Data

Weight-loss measurements represent the difference in the weight of a specimen before exposure and the weight of the exposed specimen after electro-cleaning. Complete tabulations of data for total weight-loss and weight-loss per unit area of new specimen for each specimen exposed without and with CI-2 in the fuel are shown in Tables 56 and 57 of Appendix 4 respectively. Examination of metal-weight-loss data has indicated, as in previous programs (12, 14), a uniform coefficient of variation; hence, the analysis was based on the logarithms of weight-loss per unit area data.

Specimens of bare B-1900, Mar M-246, Mar M-200, and IN-100 were exposed in each of the three rows of the specimen retainer in the test using a fuel containing no CI-2 and in only the third row of the specimen retainer in the test using 0.1 volume per cent CI-2 in the fuel. A summary of weight-loss data and visual ratings for specimens exposed in the same position in each of the two tests is shown in Table 14.

4.5.1. Precision

In the current investigation, estimates of the precision of specimen weight-loss measurements were obtained from a limited number of bare and coated superalloys exposed in duplicate. In addition to the data from the tests with and without 0.1 volume per cent CI-2 in a fuel containing 0.040 weight per cent sulfur, data were also available for specimens exposed with a fuel containing 0.0004 weight per cent sulfur (CI-2 free) and the data were pooled to provide estimates of experimental error. Duplicate specimens were exposed in the same row in the specimen retainer but at different periods during the test to include start-up and shut-down variables in the error terms. The number of specimens exposed in duplicate was limited by the amount of test time available for the investigation; however, the materials selected covered the estimated range of resistance to hot-corrosion attack and should provide valid estimates of precision of the weight-loss data. For coated superalloys the estimate of precision of logarithms of weight-loss per unit area was calculated to be $\hat{\sigma}^2_C = 0.10898$ (21 degrees of freedom). For bare superalloys the estimate of precision of logarithms of weight-loss per unit area was calculated to be $\hat{\sigma}^2_B = 0.03551$ (85 degrees of freedom). These values will be used in AOV's to determine significant effects on hot corrosion and will be used to calculate the appropriate TSM for comparisons of means.

In the previous investigation (11) three bare superalloys were exposed in duplicate in each of the three rows of the specimen retainer to provide an estimate of the relative severity of the three rows in the specimen retainer to hot-corrosion attack on the specimens. An AOV of the data obtained with 0.040 and 0.0004 weight per cent sulfur in fuel indicated a significant main effect, at the 95 per cent confidence level for rows in the retainer. No interaction for the effect of rows with any of the other variables was found. Comparisons of the means for the three rows showed no statistically significant difference for Row 1 and Row 2, but Row 3 was statistically different from Row 1 and Row 2. In the previous investigation (11) no information was available to obtain an estimate of the effect of rows on hot corrosion of coated superalloys. Since a statistically significant row effect

TABLE 14

SUMMERY OF VISUAL RATINGS AND WEIGHT LOSS DATA FOR TEST SPECIMENS

Superalloy	Coating	(a) Position	Exposure Time, hrs	No Additive (b) Visual Rating	No Additive (b) Weight Loss, mg/cm^2	0.1 % CI-2 (c) Visual Rating	0.1 % CI-2 (c) Weight Loss, mg/cm^2
B-1900	None	3A	5	9	3.44	7	8.99
B-1900	None	3A	5	9	1.96	6	8.74
B-1900	None	3C	10	7	21.04	6	36.67
B-1900	None	3B	15	6	68.18	5	92.50
B-1900	None	3B	15	8	52.30	5	105.01
B-1900	None	3D	20	7	132.64	5	164.75
B-1900	MDC-1	2D	40	6	68.81*	8	3.93
B-1900	MDC-1	2C	50	7	14.03*	7	4.33
B-1900	MDC-1	2B	60	6	34.66*	7	5.41
B-1900	MDC-1	2A	80	6	78.78	7	7.44
B-1900	MDC-9	2A	80	9	5.40	7	4.12
B-1900	MDC-9	2B	90	9	5.04	7	3.30
B-1900	MDC-9	2C	100	8	4.28	7	5.99
B-1900	MDC-9	2D	110	9	6.66*	7	4.54
Mar M-246	None	3A	5	7	37.47	6	33.63
Mar M-246	None	3A	5	8	13.49	6	40.77
Mar M-246	None	3D	10	7	43.19	5	99.08
Mar M-246	None	3B	15	7	83.70	3	148.23
Mar M-246	None	3B	15	6	80.82	5	144.32
Mar M-246	None	3D	20	6	143.64	4	199.37
Mar M-246	MDC-1	2H	40	6	73.60*	8	5.03
Mar M-246	MDC-1	2G	50	7	8.52*	7	5.22
Mar M-246	MDC-1	2F	60	8	21.70*	7	5.06
Mar M-246	MDC-1	2E	80	6	76.21*	6	8.44
Mar M-246	MDC-9	2E	80	9	4.77	7	4.37
Mar M-246	MDC-9	2F	90	9	4.38	7	4.36
Mar M-246	MDC-9	2G	100	9	4.14	7	5.27
Mar M-246	MDC-9	2H	110	9	6.25*	7	5.90*
Mar M-200	None	3A	5	7	31.64	6	53.42
Mar M-200	None	3A	5	7	29.61	6	54.83
Mar M-200	None	3A	10	6	44.04	5	86.94
Mar M-200	None	3C	15	7	132.67	6	131.58
Mar M-200	None	3C	15	8	110.57	4	134.67
Mar M-200	None	3D	20	8	142.38	6	201.60

TABLE 14 (Cont'd)

				No Additive (b)		0.1% CI-2 (c)	
Superalloy	Coating	(a) Position	Exposure Time, hrs	Visual Rating	Weight Loss, mg/cm^2	Visual Rating	Weight Loss, mg/cm^2
Mar M-200	MDC-1	2M	40	7	34.96	7	3.89
Mar M-200	MDC-1	2L	50	6	78.49	8	4.30
Mar M-200	MDC-1	2K	60	4	131.36	7	4.87
Mar M-200	MDC-1	2J	80	5	206.96	7	11.40
Mar M-200	MDC-9	2J	80	6	41.49*	7	37.52*
Mar M-200	MDC-9	2K	90	9	6.97*	6	12.51*
Mar M-200	MDC-9	2L	100	7	12.89*	5	17.12*
Mar M-200	MDC-9	2M	110	6	27.20*	5	56.50*
IN-100	None	3A	5	6	29.79	6	28.86
IN-100	None	3A	5	8	6.86	6	23.26
IN-100	None	3B	10	7	45.33	5	51.85
IN-100	None	3C	15	6	93.78	6	125.44
IN-100	None	3C	15	8	73.17	6	129.49
IN-100	None	3A	20	7	130.94	5	182.50
IN-100	MDC-1	2R	40	6	66.30	7	15.46*
IN-100	MDC-1	2Q	50	4	176.92	5	77.69
IN-100	MDC-1	2P	60	4	234.29	3	238.03
IN-100	MDC-1	2N	80	3	356.56	2	433.28
IN-100	MDC-9	2N	45	8	3.03	5	9.95*
IN-100	MDC-9	2P	55	6	33.81*	6	2.38
IN-100	MDC-9	2Q	65	4	203.96	6	2.85
IN-100	MDC-9	2R	80	3	171.31	4	128.18
Inconel 713C	None	1K	10	6	26.22	5	35.75
Inconel 713C	None	1N	10	7	27.92	7	47.38
Inconel 713C	None	1K	20	6	68.39	5	115.48
Inconel 713C	None	1N	20	7	74.25	5	126.00
Inconel 713C	None	1L	30	6	130.81	4	172.09
Inconel 713C	None	1L	30	6	165.11	4	160.65
Inconel 713C	None	1M	40	5	180.16	3	257.99
Inconel 713C	None	1M	40	5	219.68	4	212.05
Inconel 713C	MDC-1	1E	35	7	7.15	9	3.53
Inconel 713C	MDC-1	1H	40	8	3.65	7	4.19
Inconel 713C	MDC-1	1F	50	5	50.27	8	6.40
Inconel 713C	MDC-1	1G	50	6	23.04	7	4.43
Inconel 713C	MDC-1	1G	65	5	146.53	8	7.71
Inconel 713C	MDC-1	1F	65	6	35.17	5	34.77*
Inconel 713C	MDC-1	1H	80	4	195.80	7	14.88
Inconel 713C	MDC-1	1E	80	5	66.76	7	9.66

TABLE 14 (Cont'd)

Superalloy	Coating	(a) Position	Exposure Time, hrs	No Additive (b) Visual Rating	No Additive (b) Weight Loss mg/cm^2	0.1% CI-2 (c) Visual Rating	0.1% CI-2 (c) Weight Loss, mg/cm^2
Inconel 713C	MDC-9	3J	165	3	272.36	6	12.19*
Inconel 713C	MDC-9	3K	165	3	236.33	7	8.74
Udimet 700	None	1D	10	9	5.13	8	10.46
Udimet 700	None	1D	10	9	4.30	6	13.49
Udimet 700	None	1L	20	6	36.84	4	98.09
Udimet 700	None	1M	20	8	29.44	5	76.26
Udimet 700	None	1C	30	6	109.47	5	127.22
Udimet 700	None	1C	30	6	86.07	5	169.88
Udimet 700	None	1D	40	6	139.38	4	206.94
Udimet 700	None	1D	40	6	145.84	4	213.03
Udimet 700	MDC-1	1M	40	7	15.42	9	4.02
Udimet 700	MDC-1	1L	50	6	33.31	8	6.17
Udimet 700	MDC-1	1K	65	5	97.97	7	8.26
Udimet 700	MDC-1	1J	80	4	129.18	5	24.72
Udimet 700	MDC-9	3L	75	6	47.38	6	12.62*
Udimet 700	MDC-9	3M	75	7	8.16	6	10.81
Udimet 700	MDC-9	3L	90	6	23.88	5	56.61
Udimet 700	MDC-9	3M	90	5	70.68	7	7.71
IN-738	None	1E	10	9	5.88	6	21.30
IN-738	None	1M	20	8	12.96	6	60.85
IN-738	None	1L	30	7	31.14	4	99.96
IN-738	None	1Q	40	7	56.67	3	167.14
IN-738	None	1J	60	6	156.49	2	333.05
IN-738	MDC-1	1F	40	9	4.21	7	4.38
IN-738	MDC-1	1D	50	7	8.78	7	4.08
IN-738	MDC-1	1C	65	7	13.41	8	3.83
IN-738	MDC-1	1B	80	5	47.70	8	5.60
IN-738	MDC-1	1A	95	5	57.65	7	8.45
IN-738	MDC-9	3N	165	4	82.66	6	16.98*
IN-738	MDC-9	3P	165	3	152.17	3	173.79
Udimet 710	None	1E	10	9	5.41	7	8.29
Udimet 710	None	1J	20	7	14.28	7	12.69
Udimet 710	None	1H	30	7	19.66	7	26.24
Udimet 710	None	1Q	40	7	65.41	3	113.82
Udimet 710	None	1N	60	6	108.94	3	227.76
Udimet 710	None	1P	80	6	190.60	2	408.12

TABLE 14 (Cont'd)

Superalloy	Coating	(a) Position	Exposure Time, hrs	No Additive (b) Visual Rating	No Additive (b) Weight Loss, mg/cm²	0.1% CI-2 (c) Visual Rating	0.1% CI-2 (c) Weight Loss, mg/cm²
Udimet 710	MDC-1	1G	40	7	8.98	7	5.10
Udimet 710	MDC-1	1N	50	7	9.92	8	7.23*
Udimet 710	MDC-1	1P	65	6	29.55	7	13.04*
Udimet 710	MDC-1	1Q	80	5	73.55	5	25.32*
Udimet 710	MDC-1	1R	95	5	95.79	5	84.27
Udimet 710	MDC-9	3R	55	7	6.12	6	3.97
Udimet 710	MDC-9	3Q	75	7	8.58	7	6.87
Udimet 710	MDC-9	3Q	90	4	56.65	5	32.03
Udimet 710	MDC-9	3R	110	6	35.78	7	7.69
WI-52	None	2N	20	7	27.14	8	38.46
WI-52	None	3H	25	7	47.37	6	45.10
WI-52	None	3G	40	7	89.07	6	48.61
WI-52	None	3F	55	6	103.32	6	57.65
WI-52	None	3E	70	6	125.52	6	69.18
WI-52	MDC-9	1A	70	9	2.15	5	19.77
Mar M-509	None	3D	20	9	9.34	7	18.92
Mar M-509	None	3A	25	9	20.70	9	16.53
Mar M-509	None	3B	40	7	22.95	5	26.22
Mar M-509	None	3C	40	8	21.78	6	24.82
Mar M-509	None	3C	55	7	31.89	6	39.64
Mar M-509	None	3B	55	8	33.85	7	38.58
Mar M-509	None	3D	70	6	38.16	5	57.79
Mar M-509	None	3A	70	7	53.35	7	60.98
Mar M-509	MDC-9	1B	70	9	7.22	7	11.94
Mar M-302	None	2P	20	8	12.13	7	22.62
Mar M-302	None	3H	25	8	21.18	6	24.44
Mar M-302	None	3G	40	8	34.83	6	23.57
Mar M-302	None	3F	55	7	41.52	7	45.23
Mar M-302	None	3E	70	7	53.84	6	77.23
Mar M-302	MDC-9	1K	70	6	50.32*	6	15.33

TABLE 14 (Cont'd)

Superalloy	Coating	(a) Position	Exposure Time, hrs	No Additive (b) Visual Rating	No Additive (b) Weight Loss, mg/cm²	0.1% CI-2 (c) Visual Rating	0.1% CI-2 (c) Weight Loss, mg/cm²
X-40	None	2P	20	9	12.25	6	16.79
X-40	None	3E	25	9	11.49	8	15.44
X-40	None	3F	55	7	27.52	5	41.93
X-40	None	3G	85	6	53.40	5	80.64
X-40	None	3H	115	6	89.36	3	182.57
X-40	MDC-9	1R	70	9	2.10	6	10.72
AiResist 215	None	2F	15	9	4.65	7	8.38
AiResist 215	None	2R	40	8	14.14	6	14.65
AiResist 215	None	2Q	45	8	16.89	6	16.24

Notes:

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

(b) 1 ppm sea salt in air.
0.040 weight per cent sulfur in fuel.

(c) 1 ppm sea salt in air.
0.040 weight per cent sulfur and 0.10 volume per cent Ethyl CI-2 in fuel.

(*) Localized attack.

with bare superalloys was shown previously, comparisons of the relative durability of bare and coated superalloys will be limited in this study to specimens exposed in the same row in the specimen retainer. These limitations, though they curtail the number of alloy comparisons that can be made, will have no effect on the number of comparisons available to evaluate the effect of CI-2 in the fuel on hot corrosion, since specimens were exposed for the same length of time and in the same location with and without CI-2 in the fuel.

An AOV of the logarithms of weight-loss per unit area data for each possible comparison was made and on the basis of the indicated significant main effects or interactions, the necessary comparison tables of the appropriate means were made and are provided. In addition to the comparisons made on the basis of the logarithms of arithmetic means, the comparison tables include the related geometric means of the data.

4.5.2. Effect of Manganese Additive on Weight-Loss of Bare Superalloys

The AOV for logarithms of weight-loss of uncoated B-1900, Mar M-246, Mar M-200, and IN-100 indicated a significant main effect of additive-in-fuel. The average weight-loss (log mg/cm^2) for specimens exposed with and without CI-2 in the fuel were 1.84998 and 1.62536 respectively. This represents a difference of 0.22462 which exceeds the calculated TSM of 0.10878 for 24 observations and indicates an increase in weight-loss for these four superalloys when exposed in the presence of CI-2 in the fuel. Geometric means in terms of mg/cm^2 for weight-loss of specimens exposed with and without CI-2 in the fuel were 70.80 and 42.21 or a ratio of 1.68.

Means and comparisons of the weight-loss data for uncoated Udimet 700, Udimet 710, IN-738, and Inconel 713C are shown in Table 15. The addition of 0.1 volume per cent CI-2 to the fuel significantly increased the weight-loss on specimens of Udimet 700 and IN-738 but had no significant effect on the weight-loss on specimens of Inconel 713C and Udimet 710.

AOV's for the various comparisons of specimens of bare WI-52, Mar M-509, Mar M-302, and X-40 indicated no significant main effects or interactions of additives and it is concluded that the addition of 0.1 volume per cent CI-2 to the fuel had no significant effect on weight-loss with these four superalloys.

These data show that weight-loss of specimens of six bare nickel-base superalloys was increased and weight-loss of two nickel-base superalloys was not effected by the presence of 0.1 volume per cent CI-2 in fuel. Weight-loss of four bare cobalt-base superalloys was not effected by the presence of 0.1 volume per cent CI-2 in the fuel.

4.5.3. Effect of Manganese Additive on Weight-Loss of Coated Superalloys

The AOV for Misco MDC-1 coated B-1900, Mar M-246, Mar M-200, and IN-100 indicated a statistically significant interaction between additive-in-fuel and superalloys and comparisons of the effect of CI-2 in fuel are made with superalloy fixed (Table 16). The magnitude of the effect of CI-2 varied

TABLE 15

EFFECT OF CI-2 ON HOT CORROSION OF BARE SUPERALLOYS
(Udimet 700, Udimet 710, IN-738 and Inconel 713C)

Superalloy	Additive in Fuel	Mean Weight Loss at Test Hours, log mg/cm² 10	20	30	40
Inconel 713C	A_0	1.43228 (a)	1.85284 (a)	2.16718 (a)	2.29879 (a)
	A_1	1.61444 (a)	1.86905 (a)	2.22090 (a)	2.36898 (a)
Udimet 700	A_0	0.67180 (a)	1.51763 (a)	1.98708 (a)	2.15401 (a)
	A_1	1.07477 (a)	1.93696 (a)	2.16734 (a)	2.32207 (a)
IN-738	A_0	0.76938 (b)	1.11261 (b)	1.49332 (b)	1.75335 (b)
	A_1	1.32838 (b)	1.78426 (b)	1.99983 (b)	2.22298 (b)
Udimet 710	A_0	0.73320 (b)	1.15473 (b)	1.29358 (b)	1.81564 (b)
	A_1	0.91855 (b)	1.10346 (b)	1.41896 (b)	2.05622 (b)

Superalloy	Additive in Fuel	Geometric Mean Weight Loss at Test Hours, mg/cm² 10	20	30	40
Inconel 713C	A_0	27.05	71.25	146.96	198.98
	A_1	41.15	73.96	166.30	233.88
Udimet 700	A_0	4.71	32.93	97.07	142.89
	A_1	11.88	86.50	146.99	209.94
IN-738	A_0	5.88	12.96	31.14	56.63
	A_1	21.30	60.86	99.95	167.11
Udimet 710	A_0	5.41	14.28	19.66	65.40
	A_1	8.29	12.69	26.24	113.82

Superalloy	Difference $A_1 - A_0$ (log mg/cm²)	Ratio, A_1/A_0
Inconel 713C	2.01834 - 1.93777 = 0.08057 (c)	104.30 / 86.65 = 1.20
Udimet 700	1.87528 - 1.58263 = 0.29265* (c)	75.04 / 38.25 = 1.96
IN-738	1.83386 - 1.28216 = 0.55170* (d)	68.22 / 19.15 = 3.56
Udimet 710	1.37430 - 1.24929 = 0.12501 (d)	23.68 / 17.75 = 1.33

Notes: A_0 = No CI-2 in fuel and A_1 = 0.1 volume per cent CI-2 in fuel.

(a) = 2 observations
(b) = 1 observation.
(c) = TSM = 0.18841 (8 vs 8)
(d) = TSM = 0.26646 (4 vs 4)

TABLE 16

EFFECT OF CI-2 ON HOT CORROSION OF MDC-1 COATED SUPERALLOYS
(B-1900, Mar M-246, Mar M-200, and IN-100)

Additive in Fuel	Mean Weight Loss with Superalloy, log mg/cm^2			
	B-1900	MM-246	MM-200	IN-100
A_0	1.60524	1.50408	1.96818	2.24779
A_1	0.70891	0.76243	0.74196	2.02324
$A_1 - A_0$	-0.89633*	-0.74165*	-1.22622*	-0.22455

TSM = 0.46679 (4 vs 4)

Asterisk (*) indicates a significant difference at 95 per cent confidence level.

	Geometric Mean Weight Loss with Superalloy, mg/cm^2			
	B-1900	MM-246	MM-200	IN-100
A_0	40.29	31.92	92.94	176.93
A_1	5.12	5.79	5.52	105.49
A_1/A_0	0.13	0.18	0.06	0.60

A_0 = No CI-2 additive in fuel.

A_1 = 0.1 volume per cent CI-2 in fuel.

with the superalloys in this group but in all cases weight-loss was reduced and the reductions were significant for all except IN-100.

The AOV for Misco MDC-1 coated Udimet 700, Udimet 710, IN-738, and Inconel 713C indicated a significant main effect of additive-in-fuel and comparisons of the effect of CI-2 in fuel can be made on means of weight-loss averaged over superalloys and time-of-exposure. The mean logarithm of weight-loss for specimens exposed with 0.1 volume per cent CI-2 in fuel was 0.90458 and for specimens exposed in the absence of CI-2 was 1.47522. The difference of 0.57064 was greater than the calculated TSM of 0.24105 and indicated that the presence of this volume of CI-2 in the fuel reduced specimen weight-loss. The geometric means of the weight-loss of specimens exposed with and without CI-2 in fuel were 8.03 mg/cm^2 and 29.87 mg/cm^2 or a ratio of 0.27.

The weight-loss data for Misco MDC-9 coated B-1900, Mar M-246, and Mar M-200 showed no significant effect of CI-2 in fuel on specimens exposed for 80, 90, 100, and 110 hours nor for specimens of Misco MDC-9 coated B-1900, Mar M-246, Mar M-200, and IN-100 exposed for 80 hours. Specimens of IN-100 were exposed for 45, 55, and 65 hours in addition to the 80 hours of exposure for the other superalloy-coating systems. A statistically significant additive effect for the MDC-9 coated IN-100 data was indicated and means and comparisons are shown in Table 17. For specimens exposed for 55 and 65 hours the presence of CI-2 in the fuel significantly reduced specimen weight-loss.

No statistically significant effect of CI-2 in fuel was indicated for MDC-9 coated Udimet 700 and Udimet 710 specimens exposed for 75 and 90 hours.

A statistically significant effect of CI-2 in fuel was indicated for duplicate specimens of Misco MDC-9 coated Inconel 713 and IN-738 exposed for 165 hours. The mean logarithm of weight-loss for specimens of MDC-9 coated Inconel 713C with and without CI-2 in fuel was 1.01376 and 2.40433 respectively. The difference of 1.39057 exceeds the TSM of 0.66014 and indicates the presence of CI-2 in fuel reduced the weight-loss of MDC-9 coated Inconel 713C. The mean logarithms of weight-loss for Misco MDC-9 coated IN-738 specimens exposed with and without 0.1 volume per cent CI-2 in fuel were 1.73498 and 2.01981 respectively. The difference of 0.31483 was less than the TSM of 0.66014 and indicates no significant effect of CI-2 in fuel on weight-loss of MDC-9 coated IN-738.

An AOV of the weight-loss data for single specimens of MDC-9 coated WI-52, Mar M-509, Mar M-302, and X-40 indicated a significant effect of CI-2 in fuel on hot corrosion. Means and comparisons of the data are shown in Table 18 where the only significant difference is an increase in weight-loss of MDC-9 coated WI-52 with the presence of CI-2 in fuel.

These data show that seven of the eight Misco MDC-1 coated superalloy-coating systems had greater weight-loss when exposed in the absence of CI-2 in fuel than when CI-2 was present. There was no significant difference in weight-loss for MDC-1 coated IN-100 exposed with or without CI-2 in fuel. Of the eight MDC-9 coated nickel-base superalloys, six showed no difference in weight-loss with or without CI-2 in fuel, IN-100 showed a decrease in weight-loss with CI-2 in fuel at two of the four times of exposure, and

TABLE 17

EFFECT OF CI-2 ON HOT CORROSION OF MDC-9 COATED IN-100

Additive in Fuel	Mean Weight Loss With Hours of Exposure, log mg/cm^2 45	55	65	80
A_0	0.48144	1.52905	2.30955	2.23378
A_1	0.99782	0.37658	0.45484	2.10782
$A_1 - A_0$	0.51638	-1.15247*	-1.85471*	-0.12596

TSM = 0.93358

Asterisk (*) indicates a significant difference at 95 per cent confidence level.

	Geometric Mean Weight Loss With Hours of Exposure, mg/cm^2 45	55	65	80
A_0	9.95	2.38	2.85	128.17
A_1	3.03	33.81	203.99	171.32
A_1/A_0	3.28	0.07	0.01	0.75

A_0 = No CI-2 in fuel.

A_1 = 0.1 volume per cent CI-2 in fuel.

TABLE 18

EFFECT OF CI-2 ON HOT CORROSION OF MDC-9 COATED SUPERALLOYS
(WI-52, Mar M-509, Mar M-302, and X-40)

70 hours exposure

Additive in Fuel	Mean Weight Loss With Superalloy, log mg/cm²			
	WI-52	MM-509	MM-302	X-40
A_0	0.33244	0.85854	1.70174	0.32222
A_1	1.29601	1.07700	1.18554	1.03019
$A_1 - A_0$	0.96357*	0.21846	-0.51620	0.70797

TSM = 0.93358

Asterisk (*) indicates a significant difference at 95 per cent confidence level.

	Geometric Mean Weight Loss With Superalloy, mg/cm²			
	WI-52	MM-509	MM-302	X-40
A_0	2.15	7.22	50.32	2.10
A_1	19.77	11.94	15.33	10.72
A_1/A_0	9.20	1.65	0.30	5.10

A_0 = No CI-2 additive in fuel.

A_1 = 0.1 volume per cent CI-2 in fuel.

Inconel 713C showed a decrease in weight-loss for specimens exposed in the presence of CI-2 in fuel. Of the four MDC-9 coated cobalt-base superalloy-coating systems the presence of CI-2 in fuel had no significant effect on weight-loss for three of the superalloy-coating systems and significantly increased weight-loss with MDC-9 coated WI-52.

A summary of the effect of CI-2 in the fuel on hot corrosion, as measured by weight-loss, is shown in Figure 48 for the bare and coated superalloys tested.

4.5.4. Durability of Bare Superalloys (Weight-Loss)

The means of comparisons of logarithms of weight-loss indicated by the AOV of the data for uncoated B-1900, Mar M-246, Mar M-200, and IN-100 are shown in Table 19. Statistically significant differences in weight-loss for the four superalloys are shown for only the five-hour exposure level where the weight-loss of specimens of B-1900 is less than for IN-100 and IN-100 is less than for Mar M-200.

Means and comparisons of logarithms of weight-loss for uncoated Udimet 700, Udimet 710, IN-738, and Inconel 713C are shown in Table 20. The AOV of the data indicated statistically significant interactions of superalloys by time-of-exposure and superalloys by fuel-additive; thus, comparisons are made with time-of-exposure and fuel-additive fixed. The relative order of attack on these four superalloys varies with time-of-exposure and fuel-additive; however, when statistically significant differences are found, the weight-loss for Udimet 710 is the least or in the lowest group and the weight-loss for Inconel 713C is the highest or in the highest group.

AOV's of the data for bare WI-52, Mar M-509, Mar M-302, and X-40 indicated significant main effects of superalloys on weight-loss and means and comparisons of the data are shown in Table 21. In both comparisons the weight-loss with WI-52 is greater than for the other two or three superalloys.

An overall comparison of these bare superalloys was not available because of different lengths of exposure and location in different rows of the specimen retainer.

4.5.5. Durability of Coated Superalloys (Weight-Loss)

The AOV of weight-loss data for specimens of Misco MDC-1 coated B-1900, Mar M-246, Mar M-200, and IN-100 indicated a statistically significant interaction between additive-in-fuel and superalloy-coating system and comparisons should be made with fuel-additive fixed. Means and comparisons of the data are shown in Table 22. In the absence of CI-2 in the fuel the weight-loss for specimens of IN-100 is significantly greater than weight-loss for specimens of Mar M-246 or B-1900 and in the presence of CI-2 in the fuel the weight-loss for specimens of IN-100 is greater than weight-loss for specimens of B-1900, Mar M-200 or Mar M-246.

The AOV of the weight-loss data for specimens of MDC-1 coated Udimet 700, Udimet 710, IN-738, and Inconel 713C indicated a statistically significant main effect of superalloys on weight-loss and the means and comparisons

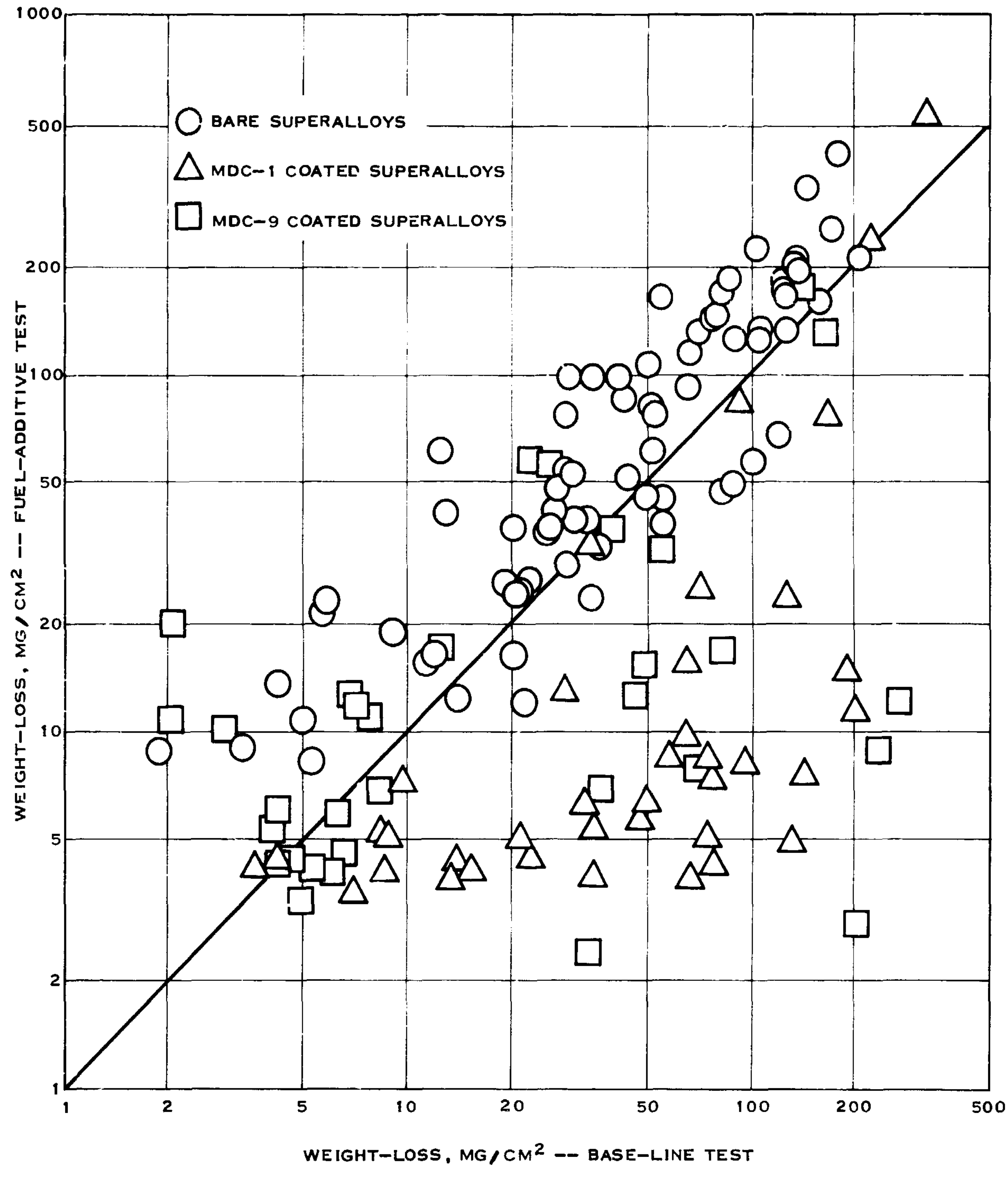


FIGURE 48
EFFECT OF CI-2 IN FUEL ON WEIGHT-LOSS

TABLE 19

COMPARISON OF HOT CORROSION OF BARE SUPERALLOYS
(B-1900, Mar M-246, Mar M-200, and IN-100)

Exposure Time, hrs	Mean Weight Loss, log mg/cm^2				Geometric Mean Weight Loss, mg/cm^2			
	TSM = 0.26646 (4 vs 4)							
5	B-1900	IN-100	MM-246	MM-200	B-1900	IN-100	MM-246	MM-200
	0.68102	1.28432	1.46019	1.60960	4.80	19.24	28.85	40.70
	TSM = 0.37682 (2 vs 2)							
10	B-1900	IN-100	MM-200	MM-246	B-1900	IN-100	MM-200	MM-246
	1.44368	1.68557	1.79154	1.81570	27.78	48.48	61.87	65.42
	TSM = 0.26646 (4 vs 4)							
15	B-1900	IN-100	MM-246	MM-200	B-1900	IN-100	MM-246	MM-200
	1.88488	2.01175	2.04009	2.10378	76.72	102.75	109.67	127.00
	TSM = 0.37682 (2 vs 2)							
20	B-1900	IN-100	MM-246	MM-200	B-1900	IN-100	MM-246	MM-200
	2.16975	2.18910	2.22844	2.22900	147.84	154.56	169.20	169.43

TABLE 20

COMPARISON OF HOT CORROSION OF BARE SUPERALLOYS
(Udimet 700, Udimet 710, IN-738, and Inconel 713C)

Additive in Fuel	Mean Weight Loss, log mg/cm²				Geometric Mean Weight Loss, mg/cm²			
	10 hours							
	(2)	(1)	(1)	(2)				
A_0	U-700	U-710	IN-738	I-713C	U-700	U-710	IN-738	I-713C
	0.67180	0.73320	0.76938	1.43228	4.70	5.41	5.88	27.12
	(1)	(2)	(1)	(2)				
A_1	U-710	U-700	IN-738	I-713C	U-710	U-700	IN-738	I-713C
	0.91855	1.07477	1.32838	1.61444	8.29	11.88	21.30	41.15
	20 hours							
	(1)	(1)	(2)	(2)				
A_0	IN-738	U-710	U-700	I-713C	IN-738	U-710	U-700	I-713C
	1.11261	1.15473	1.51763	1.85284	12.96	14.28	32.93	71.25
	(1)	(1)	(2)	(2)				
A_1	U-710	IN-738	I-713C	U-700	U-710	IN-738	I-713C	U-700
	1.10346	1.78426	1.86905	1.93696	12.69	60.86	73.96	86.50
	30 hours							
	(1)	(1)	(2)	(2)				
A_0	U-710	IN-738	U-700	IN-713C	U-710	IN-738	U-700	I-713C
	1.29358	1.49332	1.98708	2.16718	19.66	31.14	92.07	146.96
	(1)	(1)	(2)	(2)				
A_1	U-710	IN-738	U-700	I-713C	U-710	IN-738	U-700	I-713C
	1.41896	1.99983	2.16734	2.22090	26.24	99.95	146.99	166.30
	40 hours							
	(1)	(1)	(2)	(2)				
A_0	IN-738	U-710	U-700	I-713C	IN-738	U-710	U-700	I-713C
	1.75335	1.81564	2.15401	2.29879	56.68	65.40	142.56	198.98
	(1)	(1)	(2)	(2)				
A_1	U-710	IN-738	U-700	I-713C	U-710	IN-738	U-700	I-713C
	2.05622	2.22298	2.32207	2.36898	113.82	167.11	209.94	233.88

Notes: A_0 = No CI-2 in fuel and A_1 = 0.1 volume per cent CI-2 in fuel.

(1) = 1 observation and (2) = 2 observations.

TSM = 0.53291 (1 vs 1), TSM = 0.46158 (1 vs 2), and TSM = 0.37682 (2 vs 2)

TABLE 21

COMPARISONS OF HOT CORROSION OF BARE SUPERALLOYS (WI-52, Mar M-509, Mar M-302, and X-40)

Mean Weight Loss, log mg/cm²				Geometric Mean Weight Loss, mg/cm²			
25, 40, 55, and 70 hours							
(14)	(8)	(8)					
MM-509	MM-302	WI-52		MM-509	MM-302	WI-52	
1.50857	1.56511	1.83498		32.26	36.74	68.39	
25 and 55 hours							
(4)	(6)	(4)	(4)				
X-40	MM-509	MM-302	WI-52	X-40	MM-509	MM-302	WI-52
1.32779	1.45866	1.49693	1.77617	21.27	28.75	31.40	59.73

Notes:

Values in parenthesis ( ) indicate number of observations.

TSM = 0.18841 (8 vs 8)
TSM = 0.16703 (8 vs 14)
TSM = 0.26646 (4 vs 4)
TSM = 0.24328 (4 vs 6)

TABLE 22

COMPARISON OF HOT CORROSION OF MDC-1 COATED SUPERALLOYS

Additive in Fuel	Mean Weight Loss, log mg/cm^2				Geometric Mean Weight Loss, mg/cm^2			
	40, 50, 60, and 80 hours							
	(4)	(4)	(4)	(4)				
A_0	MM-246	B-1900	MM-200	IN-100	MM-246	B-1900	MM-200	IN-100
	1.50408	1.60524	1.96818	2.24779	31.92	40.29	92.94	177.34
	(4)	(4)	(4)	(4)				
A_1	B-1900	MM-200	MM-246	IN-100	B-1900	MM-200	MM-246	IN-100
	0.70891	0.74196	0.76243	2.02324	5.11	5.52	5.79	105.49
	40, 50, 65, and 80 hours							
	(8)	(8)	(8)	(14)				
A_0 & A_1	IN-738	U-710	I-713C	U-700	IN-738	U-710	I-713C	U-700
	0.86947	1.17155	1.27617	1.29393	7.40	14.85	18.89	19.67

Notes:

A_0 = No CI-2 in fuel and A_1 = 0.1 volume per cent CI-2 in fuel.

Values in parenthesis ( ) indicate number of observations.

TSM = 0.46679 (4 vs 4)
TSM = 0.33007 (8 vs 8)
TSM = 0.29262 (8 vs 14)

are shown in Table 22. These data show that there is no significant difference in weight-loss between IN-738 and Udimet 710 but the weight-loss of IN-738 is significantly less than for Inconel 713C or Udimet 700.

Means and comparisons of weight-loss for Misco MDC-9 coated superalloys for which the AOV's indicated statistically significant differences are shown in Table 23. In the comparison of MDC-9 coated B-1900, Mar M-246, and Mar M-200 the weight-loss with Mar M-200 was significantly greater than for B-1900 or Mar M-246. In the comparison of the four superalloy-coating systems exposed for 80 hours the weight-loss for IN-100 and Mar M-200 were not significantly different but both were significantly greater than for Mar M-246 and B-1900.

Specimens of MDC-9 coated Udimet 700 and Udimet 710 exposed for 75 and 90 hours indicated no statistically significant difference in weight-loss.

Duplicate specimens of MDC-9 coated Inconel 713C and IN-738 exposed for 165 hours indicate no statistically significant difference in weight-loss either with or without CI-2 in the fuel.

In the absence of CI-2 in the fuel the weight-loss for specimens of MDC-9 coated Mar M-302 was significantly greater than for specimens of MDC-9 coated X-40 or WI-52 but was not significantly different from the weight-loss for MDC-9 coated Mar M-509. In the presence of 0.1 volume per cent CI-2 in fuel there were no statistically significant differences in the weight-loss for specimens of the four superalloy-coating systems.

Specimens of bare and MDC-1 coated Udimet 700, Udimet 710, IN-738, and Inconel 713C were exposed for the same lengths of time in the same row of the retainer and provide an evaluation of the effect of the coating on durability of the materials. Means and comparisons of the weight-loss data are presented in Table 24 on the basis of the AOV of the data. While the magnitude of the difference depends on the presence or absence of fuel additive, the weight-loss with the bare superalloys is greater than with the four superalloy-coating systems.

Specimens of Misco MDC-1 and MDC-9 coated B-1900, Mar M-246, Mar M-200, and IN-100 were exposed in the same row in the specimen retainer for the same lengths of time and provide a comparison of the relative durability of the coatings on these superalloys. The AOV of the data indicated a statistically significant coating by fuel-additive interaction and the means and comparisons in Table 25 are presented on this basis. These comparisons show that weight-loss with MDC-1 coated superalloys is significantly greater than with the MDC-9 coated superalloys in the absence of CI-2 in the fuel and there is no significant difference in weight-loss with the two coatings on these superalloys exposed in the presence of 0.1 volume per cent CI-2 in the fuel.

TABLE 23

COMPARISON OF HOT CORROSION OF MDC-9 COATED SUPERALLOYS

Additive in Fuel	Mean Weight Loss, log mg/cm^2				Geometric Mean Weight Loss, mg/cm^2			
	80, 90, 100, and 110 hours							
	(8)	(8)	(8)					
A_0 & A_1	B-1900	MM-246	MM-200		B-1900	MM-246	MM-200	
	0.68220	[illegible]	1.33288		4.81	4.88	21.52	
	80 hours							
	(2)	(2)	(2)	(2)				
A_0 & A_1	MM-246	B-1900	MM-200	IN-100	MM-246	B-1900	MM-200	IN-100
	0.65950	0.67365	1.59610	2.17080	4.57	4.72	39.45	148.18
	165 hours							
	(2)	(2)						
A_0	IN-738	I-713C			IN-738	I-713C		
	2.04981	2.40433			112.15	253.69		
	(2)	(2)						
A_1	I-713C	IN-738			I-713C	IN-738		
	1.01376	1.73498			10.32	54.32		
	70 hours							
	(1)	(1)	(1)	(1)				
A_0	X-40	WI-52	MM-509	MM-302	X-40	WI-52	MM-509	MM-302
	0.3222	0.33244	0.85854	1.70174	2.10	2.15	7.22	50.32
	(1)	(1)	(1)	(1)				
A_1	X-40	MM-509	MM-302	WI-52	X-40	MM-509	MM-302	WI-52
	1.03019	1.07700	1.18554	1.29601	10.72	11.94	15.33	19.70

Notes:

A_0 = No CI-2 in fuel and A_1 = 0.1 volume per cent CI-2 in fuel.

Values in parenthesis ( ) indicate number of observations.

TSM = 0.33007 (8 vs 8)
TSM = 0.66014 (2 vs 2)
TSM = 0.93358 (1 vs 1)

TABLE 24

COMPARISON OF WEIGHT-LOSS DATA FOR BARE VS MDC-1 COATED SUPERALLOYS
(Udimet 700, Udimet 710, IN-738, and Inconel 713C)

	Weight Loss with Fuel Additive			
	Mean, log mg/cm^2		Geometric Mean, mg/cm^2	
Coating	A_0	A_1	A_0	A_1
Bare	2.07907 (6)	2.24948 (6)	119.98	177.62
MDC-1	0.83198 (4)	0.64387 (4)	6.80	4.40
(Bare)-(MDC-1)	1.24709 *	1.60561 *		
(Bare)/(MDC-1)			17.7	40.3

Notes:

A_0 = Test fuel without CI-2 additive.

A_1 = Test fuel with 0.1 volume per cent CI-2 additive.

TSM = 0.28848 (6 vs 4)

Asterisk (*) indicates a significant difference at 95 per cent confidence level.

Value in parenthesis ( ) indicates number of observations in mean.

TABLE 25

COMPARISON OF WEIGHT-LOSS DATA FOR MDC-1 VS MDC-9 COATED SUPERALLOYS
(B-1900, Mar M-246, Mar M-200, and IN-100)

	Weight Loss with Fuel Additive			
	Mean, log mg/cm^2		Geometric Mean, mg/cm^2	
Coating	A_0	A_1	A_0	A_1
MDC-1	2.16161 (4)	1.37290 (4)	145.08	23.60
MDC-9	1.31556 (4)	1.23437 (4)	20.69	17.16
(MDC-1)-(MDC-9)	0.84595 *	0.13853		
(MDC-1)/(MDC_9)			7.0	1.4

Notes:

A_0 = Test fuel without CI-2 additive.

A_1 = Test with 0.1 volume per cent CI-2 additive.

TSM = 0.31637 (4 vs 4)

Asterisk (*) indicates a significant difference at 95 per cent confidence level.

Value in parenthesis ( ) indicates number of observations in mean.

4.6. Metallographic-Penetration Data

All specimens exposed in the presence of 0.1 volume per cent CI-2 in the fuel and the corresponding specimens exposed in the base line test were examined metallographically to determine the mean surface-loss (mils) and maximum penetration (mils) using the technique described in Appendix 3, Section 10.3. The detailed data showing the surface-loss for the two diameters at the location of average visual attack, the surface-loss for the two diameters at the location of maximum visual attack and the mean of the four values for the base line test are presented in Table 58 of Appendix 4 (Section 11.4.) and for the fuel-additive test in Table 59 of Appendix 4. The detailed data for maximum attack at the locations of average and maximum visual attack and the maximum penetration for the base line and fuel-additive tests are shown in Tables 60 and 61 of Appendix 4, Section 11.4. These tables show the variation of loss for individual specimens; however, for analyses of the data the mean of the surface-loss (mils) and the maximum penetration were used in accordance with the test technique and the data for the two tests are summarized in Table 26.

4.6.1. Precision

Estimates of the precision of the surface-loss and penetration data were obtained from the same limited number of specimens of bare and coated superalloys that were exposed in duplicate and were used in determining precision of the surface-scale and weight-loss data.

For bare superalloys the estimate of precision of the surface-loss data was calculated to be $\hat{\sigma}^2_B = 6.90$ (38 degrees of freedom) and for the coated superalloys the estimate of precision of the surface-loss data was $\hat{\sigma}^2_C = 49.29$ (14 degrees of freedom).

The precision of the maximum penetration data was estimated to be $\hat{\sigma}^2_B = 24.74$ (38 degrees of freedom) for the bare superalloys and $\hat{\sigma}^2_C = 225.93$ (14 degrees of freedom) for the coated superalloys.

In all comparisons of the effect of CI-2 in the fuel on surface-loss or maximum penetration, data are available on specimens exposed in the same location and for the same length of time without and with 0.1 volume per cent CI-2 in the fuel to provide direct comparisons. Comparisons of surface-loss or maximum penetration for superalloys or superalloy-coating systems will be confined to specimens exposed within a row of the specimen retainer. All comparisons will be made on the basis of the indicated statistically significant effects shown by AOV's of the data.

4.6.2. Effect of Manganese Additive on Surface-Loss of Bare Superalloys

The AOV of surface-loss data for uncoated B-1900, Mar M-246, Mar M-200, and IN-100 indicates statistically significant interactions of superalloys by additives and time-of-exposure by additives and means and comparisons of the effect of CI-2 in fuel are made with time-of-exposure and superalloy fixed (Table 27). The presence of CI-2 in the fuel had no statistically significant effect on surface-loss for specimens of Mar M-200 but had a

TABLE 26

SUMMARY OF PENETRATION DATA FOR SPECIMENS

Superalloy	Coating	(a) Position	Exposure Time, hrs	No Additive (b) Surface Loss, mils (d)	No Additive (b) Maximum Attack, mils (e)	0.1 % CI-2 (c) Surface Loss, mils (d)	0.1 % CI-2 (c) Maximum Attack, mils (e)
B-1900	None	3A	5	0.8	13.5 (0)	3.2	5.6 (B)
B-1900	None	3A	5	0.3	5.8 (B)	2.4	7.5 (M)
B-1900	None	3C	10	0.8	6.0 (0)	6.8	11.8 (B)
B-1900	None	3B	15	12.9	28.8 (0)	18.5	19.6 (B)
B-1900	None	3B	15	5.9	15.6 (B)	17.4	19.9 (B)
B-1900	None	3D	20	22.9	24.8 (B)	28.4	35.1 (B)
B-1900	MDC-1	2D	40	18.5*	56.5 (0)	3.4	6.1 (B)
B-1900	MDC-1	2C	50	3.4*	9.4 (0)	3.2	7.3 (B)
B-1900	MDC-1	2B	60	9.9*	22.6 (0)	2.4	4.5 (0)
B-1900	MDC-1	2A	80	19.0	28.5 (B)	5.0	8.0 (0)
B-1900	MDC-9	2A	80	2.5	4.5 (B)	3.4	5.9 (B)
B-1900	MDC-9	2B	90	7.0	20.1 (0)	3.5	5.0 (B)
B-1900	MDC-9	2C	100	4.7	12.6 (B)	6.0	14.0 (B)
B-1900	MDC-9	2D	110	4.6*	7.1 (0)	3.8	5.6 (B)
Mar M-246	None	3A	5	10.8	14.5 (B)	8.0	14.1 (B)
Mar M-246	None	3A	5	6.5	10.4 (B)	7.8	11.3 (B)
Mar M-246	None	3D	10	9.2	13.0 (B)	16.4	20.2 (B)
Mar M-246	None	3B	15	13.6	25.5 (M)	21.6	25.9 (B)
Mar M-246	None	3B	15	12.8	19.6 (B)	25.8	42.0 (B)
Mar M-246	None	3D	20	19.2	26.5 (B)	27.2	41.5 (B)
Mar M-246	MDC-1	2H	40	6.9*	25.0 (B)	1.6	7.3 (B)
Mar M-246	MDC-1	2G	50	3.3*	8.9 (B)	5.4	16.4 (B)
Mar M-246	MDC-1	2F	60	5.5*	18.0 (M)	3.2	7.5 (B)
Mar M-246	MDC-1	2E	80	10.2*	19.5 (0)	4.6	8.8 (B)
Mar M-246	MDC-9	2E	80	4.2	5.5 (B)	0.2	5.0 (B)
Mar M-246	MDC-9	2F	90	4.4	5.8 (B)	3.8	9.8 (B)
Mar M-246	MDC-9	2G	100	6.6	10.8 (B)	2.0	4.8 (B)
Mar M-246	MDC-9	2H	110	3.7*	5.7 (B)	1.8*	4.1 (B)
Mar M-200	None	3A	5	5.7	9.4 (B)	9.5	17.4 (B)
Mar M-200	None	3A	5	7.0	9.1 (B)	6.8	11.1 (B)
Mar M-200	None	3A	10	12.5	20.0 (B)	10.0	17.5 (B)
Mar M-200	None	3C	15	21.8	30.4 (M)	16.7	26.2 (B)
Mar M-200	None	3C	15	18.6	27.6 (B)	15.9	28.9 (B)
Mar M-200	None	3D	20	21.0	35.6 (0)	26.2	35.9 (B)

TABLE 26 (Cont'd)

Superalloy	Coating	(a) Position	Exposure Time, hrs	No Additive (b) Surface Loss, mils (d)	No Additive (b) Maximum Attack, mils (e)	0.1% CI-2 (c) Surface Loss, mils (d)	0.1% CI-2 (c) Maximum Attack, mils (e)
Mar M-200	MDC-1	2M	40	9.0	18.1 (B)	3.0	6.8 (B)
Mar M-200	MDC-1	2L	50	13.6	25.9 (B)	-0.3	7.3 (B)
Mar M-200	MDC-1	2K	60	24.9	36.4 (B)	-0.6	6.1 (O)
Mar M-200	MDC-1	2J	80	47.9	59.3 (M)	3.0	9.2 (B)
Mar M-200	MDC-9	2J	80	5.5*	12.0 (B)	1.1*	4.6 (B)
Mar M-200	MDC-9	2K	90	4.0*	5.1 (B)	1.9*	4.9 (B)
Mar M-200	MDC-9	2L	100	4.3*	8.1 (O)	-1.2*	-0.2 (B)
Mar M-200	MDC-9	2M	110	4.4*	11.5 (O)	1.2*	4.2 (B)
IN-100	None	3A	5	5.5	12.4 (B)	4.4	12.2 (B)
IN-100	None	3A	5	3.4	6.0 (B)	2.9	11.4 (B)
IN-100	None	3B	10	8.4	13.5 (B)	8.0	15.8 (B)
IN-100	None	3C	15	17.2	26.4 (B)	21.2	25.0 (B)
IN-100	None	3C	15	14.1	22.1 (B)	17.1	30.6 (B)
IN-100	None	3A	20	18.0	36.4 (B)	26.2	31.0 (B)
IN-100	MDC-1	2R	40	12.8	27.6 (O)	3.0*	7.0 (B)
IN-100	MDC-1	2Q	50	27.4	56.4 (B)	18.4	36.9 (O)
IN-100	MDC-1	2P	60	49.6	69.4 (B)	40.0	87.8 (B)
IN-100	MDC-1	2N	80	69.6	98.3 (B)	52.0	62.7 (B)
IN-100	MDC-9	2N	45	4.[illegible]	6.1 (B)	4.5*	5.5 (B)
IN-100	MDC-9	2P	55	8.0*	19.8 (B)	2.2	5.2 (B)
IN-100	MDC-9	2Q	65	24.7	54.6 (B)	2.7	6.7 (B)
IN-100	MDC-9	2R	80	39.2	77.1 (B)	21.8	36.8 (B)
Inconel 713C	None	1K	10	5.2	9.6 (M)	6.2	15.4 (B)
Inconel 713C	None	1N	10	8.3	12.9 (M)	15.0	29.5 (B)
Inconel 713C	None	1K	20	13.9	19.1 (B)	16.5	23.0 (B)
Inconel 713C	None	1N	20	9.7	18.6 (M)	18.6	23.3 (B)
Inconel 713C	None	1L	30	22.6	26.9 (B)	32.4	38.7 (B)
Inconel 713C	None	1L	30	28.8	36.4 (B)	31.2	43.7 (B)
Inconel 713C	None	1M	40	30.4	43.0 (B)	30.6	50.9 (B)
Inconel 713C	None	1M	40	33.9	45.5 (B)	25.9	50.9 (B)
Inconel 713C	MDC-1	1E	35	5.4	10.8 (B)	2.4	7.6 (B)
Inconel 713C	MDC-1	1H	40	3.6	10.0 (O)	0.8	6.8 (B)
Inconel 713C	MDC-1	1F	50	15.4	31.1 (B)	3.9	6.9 (B)
Inconel 713C	MDC-1	1G	50	7.2	16.4 (B)	4.3	8.3 (B)
Inconel 713C	MDC-1	1G	65	21.9	46.5 (B)	4.8	8.1 (B)
Inconel 713C	MDC-1	1F	65	6.6	14.8 (O)	10.4*	38.1 (B)
Inconel 713C	MDC-1	1H	80	29.4	57.3 (B)	9.4	23.6 (B)
Inconel 713C	MDC-1	1E	80	15.8	26.5 (B)	4.3	8.3 (O)

TABLE 26 (Cont'd)

Superalloy	Coating	(a) Position	Exposure Time, hrs	No Additive (b) Surface Loss, mils (d)	No Additive (b) Maximum Attack, mils (e)	0.1% CI-2 (c) Surface Loss, mils (d)	0.1% CI-2 (c) Maximum Attack, mils (e)
Inconel 713C	MDC-9	3J	165	56.4	68.4 (B)	5.2*	15.0 (B)
Inconel 713C	MDC-9	3K	165	36.7	62.3 (B)	5.4	13.7 (O)
Udimet 700	None	1D	10	2.8	8.5 (M)	2.3	9.3 (B)
Udimet 700	None	1D	10	1.9	8.4 (B)	2.4	10.1 (B)
Udimet 700	None	1L	20	9.3	18.9 (B)	12.0	21.0 (B)
Udimet 700	None	1M	20	5.4	16.6 (B)	10.8	24.1 (B)
Udimet 700	None	1C	30	13.6	23.4 (B)	16.8	29.5 (B)
Udimet 700	None	1C	30	15.6	25.9 (B)	24.6	39.8 (B)
Udimet 700	None	1D	40	22.8	29.1 (B)	25.5	36.5 (B)
Udimet 700	None	1D	40	22.4	42.0 (B)	17.4	29.7 (B)
Udimet 700	MDC-1	1M	40	6.2	14.3 (B)	0.6	16.4 (B)
Udimet 700	MDC-1	1L	50	4.9	16.9 (B)	2.0	6.5 (M)
Udimet 700	MDC-1	1K	65	16.6	44.5 (B)	2.3	7.3 (M)
Udimet 700	MDC-1	1J	80	23.5	46.3 (B)	1.4	16.1 (B)
Udimet 700	MDC-9	3L	75	14.2	23.1 (M)	4.2*	8.4 (B)
Udimet 700	MDC-9	3M	75	3.6	6.6 (B)	4.2	8.4 (B)
Udimet 700	MDC-9	3L	90	5.4	11.1 (B)	4.8	20.3 (B)
Udimet 700	MDC-9	3M	90	8.1	30.1 (B)	2.6	10.8 (B)
IN-738	None	1E	10	3.5	8.5 (B)	4.9	16.4 (B)
IN-738	None	1M	20	1.6	12.6 (B)	4.8	20.0 (B)
IN-738	None	1L	30	7.4	17.8 (B)	14.1	32.1 (B)
IN-738	None	1Q	40	9.2	19.9 (B)	17.7	36.2 (B)
IN-738	None	1J	60	18.9	41.4 (B)	50.8	83.6 (B)
IN-738	MDC-1	1F	40	5.3	11.8 (M)	3.8	11.8 (B)
IN-738	MDC-1	1D	50	4.1	16.5 (M)	3.8	6.5 (B)
IN-738	MDC-1	1C	65	6.1	21.6 (M)	2.7	5.7 (B)
IN-738	MDC-1	1B	80	7.4	42.6 (M)	3.2	8.4 (B)
IN-738	MDC-1	1A	95	9.5	27.4 (B)	4.2	12.5 (O)
IN-738	MDC-9	3N	165	13.4	34.4 (B)	2.9*	6.9 (B)
IN-738	MDC-9	3P	165	22.9	46.3 (B)	18.2	57.4 (B)
Udimet 710	None	1E	10	2.2	9.1 (B)	0.2	15.5 (B)
Udimet 710	None	1J	20	4.4	16.0 (B)	2.3	15.8 (B)
Udimet 710	None	1H	30	3.0	15.5 (B)	1.4	13.7 (B)
Udimet 710	None	1Q	40	15.7	36.1 (B)	31.4	54.6 (B)
Udimet 710	None	1N	60	6.3	41.8 (B)	33.0	59.8 (B)
Udimet 710	None	1P	80	27.6	56.0 (B)	62.8	116.1 (B)

TABLE 26 (Cont'd)

Superalloy	Coating	(a) Position	Exposure Time, hrs	No Additive (b) Surface Loss, mils (d)	No Additive (b) Maximum Attack, mils (e)	0.1 % CI-2 (c) Surface Loss, mils (d)	0.1 % CI-2 (c) Maximum Attack mils (e)
Udimet 710	MDC-1	1G	40	6.1	21.5 (B)	4.8	16.1 (M)
Udimet 710	MDC-1	1N	50	3.2	8.0 (B)	0.9*	5.4 (B)
Udimet 710	MDC-1	1P	65	4.1	26.1 (B)	2.1*	8.1 (M)
Udimet 710	MDC-1	1Q	80	12.7	34.6 (B)	1.4*	9.1 (B)
Udimet 710	MDC-1	1R	95	15.0	45.0 (B)	6.8	31.3 (B)
Udimet 710	MDC-9	3R	55	4.6	12.6 (O)	3.7	7.2 (B)
Udimet 710	MDC-9	3Q	75	1.0	8.2 (O)	4.1	10.1 (O)
Udimet 710	MDC-9	3Q	90	10.6	35.6 (B)	6.9	23.9 (B)
Udimet 710	MDC-9	3R	110	6.8	18.5 (B)	3.6	8.4 (B)
WI-52	None	2N	20	8.0	12.7 (B)	4.4	11.2 (B)
WI-52	None	3H	25	10.2	17.3 (B)	12.6	17.6 (B)
WI-52	None	3G	40	9.2	18.0 (B)	9.2	16.0 (B)
WI-52	None	3F	55	15.0	30.0 (O)	5.3	13.0 (B)
WI-52	None	3E	70	19.6	34.8 (B)	8.6	21.3 (B)
WI-52	MDC-9	1A	70	6.2	8.5 (B)	9.0	14.7 (B)
Mar M-509	None	3D	20	3.8	7.0 (B)	4.1	8.6 (B)
Mar M-509	None	3A	25	4.4	10.3 (B)	2.4	6.1 (B)
Mar M-509	None	3B	40	2.2	6.9 (B)	5.4	19.6 (B)
Mar M-509	None	3C	40	4.6	11.9 (B)	8.5	19.0 (O)
Mar M-509	None	3C	55	7.1	17.1 (B)	8.5	14.0 (B)
Mar M-509	None	3B	55	5.0	11.8 (O)	3.8	7.8 (B)
Mar M-509	None	3D	70	7.3	27.3 (M)	5.5	28.0 (B)
Mar M-509	None	3A	70	7.4	16.2 (M)	8.8	17.5 (B)
Mar M-509	MDC-9	1B	70	7.0	8.8 (B)	4.6	6.6 (B)
Mar M-302	None	2P	20	2.0	5.3 (B)	3.0	3.3 (B)
Mar M-302	None	3H	25	6.1	8.5 (B)	6.9	10.4 (B)
Mar M-302	None	3G	40	7.2	19.5 (B)	5.4	8.4 (B)
Mar M-302	None	3F	55	6.5	9.8 (B)	8.4	9.2 (B)
Mar M-302	None	3E	70	7.6	17.6 (B)	7.0	13.8 (B)
Mar M-302	MDC-9	1K	70	3.5*	21.5 (B)	8.3	10.8 (B)

TABLE 26 (Cont'd)

Superalloy	Coating	(a) Position	Exposure Time, hrs	No Additive (b) Surface Loss, mils (d)	No Additive (b) Maximum Attack, mils (e)	0.1% CI-2 (c) Surface Loss, mils (d)	0.1% CI-2 (c) Maximum Attack, mils (e)
X-40	None	2P	20	4.1	15.1 (B)	2.6	12.8 (B)
X-40	None	3E	25	4.8	9.5 (B)	4.9	13.4 (B)
X-40	None	3F	55	8.6	29.5 (B)	6.2	34.9 (B)
X-40	None	3G	85	4.1	31.6 (B)	13.7	40.7 (B)
X-40	None	3H	115	10.6	45.9 (B)	16.6	58.8 (B)
X-40	MDC-9	1R	70	3.8	8.0 (B)	5.2	15.2 (B)
AiResist 215	None	2F	15	2.2	5.9 (B)	4.2	5.0 (B)
AiResist 215	None	2R	40	2.2	9.0 (B)	3.2	6.2 (B)
AiResist 215	None	2Q	45	2.4	11.1 (B)	2.4	6.9 (B)

Notes:

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Back Row.
Letter = Position in Row.

(b) 1 ppm sea salt in air.
0.040 weight per cent sulfur in fuel.

(c) 1 ppm sea salt in air.
0.040 weight per cent sulfur and 0.10 volume per cent CI-2 in fuel.

(d) Loss in diameter due to massive oxides and sulfides.

(3) Loss in diameter due to all forms of oxidation and sulfidation.

(*) Localized attack.

(B) Attack on both sides of specimen.

(M) Attack mostly on one side of specimen.

(O) Attack on one side of specimen.

TABLE 27

EFFECT OF CI-2 ON SURFACE LOSS OF BARE SUPERALLOYS
(B-1900, Mar M-246, Mar M-200, and IN-100)

Superalloy	Additive in Fuel	Mean Surface Loss at Test Hours, mils 5	10	15	20
B-1900	A_0	0.6 (2)	0.8 (1)	9.4 (2)	22.9 (1)
	A_1	2.8 (2)	6.8 (1)	18.0 (2)	28.4 (1)
Mar M-246	A_0	8.6 (2)	9.2 (1)	13.2 (2)	19.8 (1)
	A_1	7.9 (2)	16.4 (1)	23.7 (2)	27.2 (1)
Mar M-200	A_0	6.4 (2)	12.5 (1)	20.2 (2)	21.0 (1)
	A_1	8.2 (2)	10.0 (1)	16.3 (2)	26.2 (1)
IN-100	A_0	4.4 (2)	8.4 (1)	15.6 (2)	18.0 (1)
	A_1	3.6 (2)	8.0 (1)	19.2 (2)	26.2 (1)

Superalloy	Difference $A_1 - A_0$, mils, at Test Hours 5	10	15	20
B-1900	2.2	6.0	8.6*	5.5
Mar M-246	-0.7	7.2	10.5*	7.4*
Mar M-200	1.8	-2.5	-3.9	5.2
IN-100	-0.8	-0.4	-3.6	8.2*

Notes:

A_0 = Test fuel without CI-2 additive

A_1 = Test fuel with 0.1 volume per cent CI-2 additive.

Values in parentheses ( ) = number of observations in a mean.

TSM = 7.4 (1 vs 1)

TSM = 5.2 (2 vs 2)

Asterisk (*) indicates a significant effect at 95 per cent confidential level.

statistically significant effect at one or more times of exposure for the other three superalloys. In each case where CI-2 in the fuel had an effect it was to increase the depth of surface-loss.

A superalloy by time-of-exposure by fuel-additive interaction was shown in the AOV of the surface-loss data for Udimet 700, Udimet 710, IN-738, and Inconel 713C and comparisons of the effect of CI-2 in the fuel should be made with superalloys and time-of-exposure fixed. Means and comparisons are shown in Table 28. For each superalloy the presence of CI-2 in fuel significantly increased the depth of surface-loss at one or more times of exposure.

A statistically significant interaction of superalloys by additive was indicated by the AOV of the surface-loss data for specimens of bare WI-52, Mar M-509, and Mar M-302 exposed for 25, 40, 55, and 70 hours and the means and comparisons presented in Table 29 indicate that the presence of CI-2 decreased the depth of the surface-loss for WI-52 and had no significant effect on the other three superalloys. Specimens of X-40 were exposed for 25, 55, 85, and 115 hours and the presence of CI-2 in fuel significantly increased the depth of surface-loss for the specimen exposed for 85 hours but had no significant effect on the specimens exposed at the other three time periods.

For the twelve bare superalloys exposed in this program, the addition of 0.1 volume per cent CI-2 to the fuel either had no statistically significant effect, or it caused a statistically significant increase in penetration as measured by surface-loss. One exception is noted, where the addition of CI-2 to the fuel caused a statistically significant reduction in penetration with WI-52.

4.6.3. Effect of Manganese Additive on Surface-Loss of Coated Superalloys

Means and comparisons of the surface-loss data for MDC-1 coated B-1900, Mar M-246, Mar M-200, and IN-100 are shown in Table 30 for each superalloy-coating on the basis of the fuel-additive by superalloy-coating interaction found in the AOV. The means and comparison for MDC-1 coated Udimet 700, Udimet 710, IN-738, and Inconel 713C are also shown in Table 30 on the basis of a significant main effect of additives in the AOV of the surface-loss data. These comparisons indicate that CI-2 in the fuel had no statistically significant effect on surface-loss for MDC-1 coated B-1900 and Mar M-246 and significantly decreased surface-loss for the other six MDC-1 coated nickel-base superalloys.

Of the twelve MDC-9 coated superalloys, statistically significant effects of CI-2 in the fuel were indicated in only two of the AOV's and the means and comparisons to evaluate these effects are shown in Table 31. The surface-loss with CI-2 in fuel was decreased for MDC-9 coated IN-100 and Inconel 713C and had no effect for MDC-9 coated IN-738.

In Figure 49 the surface-loss measurements are shown for individual specimens of the superalloys and superalloy-coating systems exposed without and with 0.1 volume per cent CI-2 in the fuel. This figure indicates the variability of some of the individual determinations.

TABLE 28

EFFECT OF CI-2 ON SURFACE LOSS OF BARE SUPERALLOYS
(Udimet 700, Udimet 710, IN-738, and Inconel 713C)

Superalloy	Additive in Fuel	Mean Surface Loss at Test Hours, mils			
		10	20	30	40
Inco 713C	A_0	6.8 (2)	11.8 (2)	25.7 (2)	32.2 (2)
	A_1	10.6 (2)	17.6 (2)	31.8 (2)	28.2 (2)
Udimet 700	A_0	2.4 (2)	7.4 (2)	14.6 (2)	22.6 (2)
	A_1	2.4 (2)	11.4 (2)	20.7 (2)	21.4 (2)
IN-738	A_0	3.5 (1)	1.6 (1)	7.4 (1)	9.2 (1)
	A_1	4.9 (1)	4.8 (1)	14.1 (1)	17.7 (1)
Udimet 710	A_0	2.2 (1)	4.4 (1)	3.0 (1)	15.7 (1)
	A_1	0.2 (1)	2.3 (1)	[illegible]	31.4 (1)

Superalloy	Difference $A_1 - A_0$, mils, at Test Hours			
	10	20	30	40
Inco 713C	3.8	5.8*	6.1*	-4.0
Udimet 700	0.0	4.0	6.1*	-1.2
IN-738	1.4	3.2	6.7	8.5*
Udimet 710	-2.0	-2.1	-1.6	15.7*

Notes:

A_0 = Test fuel without CI-2 additive.

A_1 = Test fuel with 0.1 volume per cent CI-2 additive.

Value in parentheses ( ) = number of observations in a mean.

TSM = 7.4 (1 vs 1)

TSM = 5.2 (2 vs 2)

Asterisk (*) indicates a significant effect at 95 per cent confidence level.

TABLE 29

EFFECT OF CI-2 ON SURFACE LOSS OF BARE SUPERALLOYS
(WI-52, Mar M-509, Mar M-302, and X-40)

Superalloy	Comparison of Surface Loss at 25, 40, 55, and 70 hours — Means, mils: A_1	Means, mils: A_0	Difference, mils: $A_1 - A_0$
WI-52	9.0 (4)	13.5 (4)	-4.5 *
Mar M-509	6.1 (7)	5.4 (7)	0.7
Mar M-302	6.9 (4)	6.8 (4)	0.1

No significant additive effect for specimens of WI-52, Mar M-509, Mar M-302, and X-40 exposed for 25 and 55 hours.

X-40 @ 25 hours	4.9	4.8	0.1
X-40 @ 55 hours	6.2	8.6	-2.4
X-40 @ 85 hours	13.7	4.1	9.6 *
X-40 @ 115 hours	16.6	10.6	6.0

Notes:

A_0 = Test fuel without CI-2 additive.

A_1 = Test fuel with 0.1 volume per cent CI-2 additive.

Value in parentheses ( ) = number of observations in a mean.

TSM = 3.7 (4 vs 4)

TSM = 2.8 (7 vs 7)

TSM = 7.4 (1 vs 1)

Asterisk (*) indicates a significant effect at 95 per cent confidence level.

TABLE 30

EFFECT OF CI-2 ON SURFACE LOSS OF MDC-1 COATED SUPERALLOYS

MDC-1 Coated Superalloy	Comparison of Surface Loss at 25, 40, 55, and 70 hours: Means, mils A_1	Means, mils A_0	Difference, mils $A_1 - A_0$
B-1900	3.5 (4)	12.7 (4)	-9.2
Mar M-246	3.7 (4)	6.5 (4)	-2.8
Mar M-200	1.3 (4)	23.8 (4)	-22.5 *
IN-100	28.4 (4)	39.8 (4)	-11.4 *
Inco 713C Udimet 700 IN-738 Udimet 710	3.5 (19)	10.5 (19)	-7.0 *

Notes:

A_0 = Test fuel without CI-2 additive.

A_1 = Test fuel with 0.1 volume per cent CI-2 additive.

Value in parentheses ( ) = number of observations in a mean.

TSM = 9.9 (4 vs 4)

TSM = 4.5 (19 vs 19)

Asterisk (*) indicates a significant effect at 95 per cent confidence level.

TABLE 31

EFFECT OF CI-2 ON SURFACE LOSS OF MDC-9 COATED SUPERALLOYS

MDC-9 Coated Superalloy	Comparison of Surface Loss at Test Hours: Mean, mils A_1	Mean, mils A_0	Difference, mils $A_1 - A_0$
IN-100 (a)	7.8 (4)	19.0 (4)	-11.2 *
Inco 713C (b)	5.3 (2)	46.5 (2)	-41.2 *
IN-738 (b)	10.6 (2)	18.2 (2)	-7.6

Notes:

A_0 = Test fuel without additive.

A_1 = Test fuel with 0.1 volume per cent CI-2 additive.

Value in parentheses ( ) = number of observations in a mean.

TSM = 9.9 (4 vs 4)

TSM = 14.0 (2 vs 2)

Asterisk (*) indicates a significant effect at 95 per cent confidence level.

(a) Specimens exposed for 45, 55, 65, and 80 hours.

(b) Specimens exposed for 165 hours.

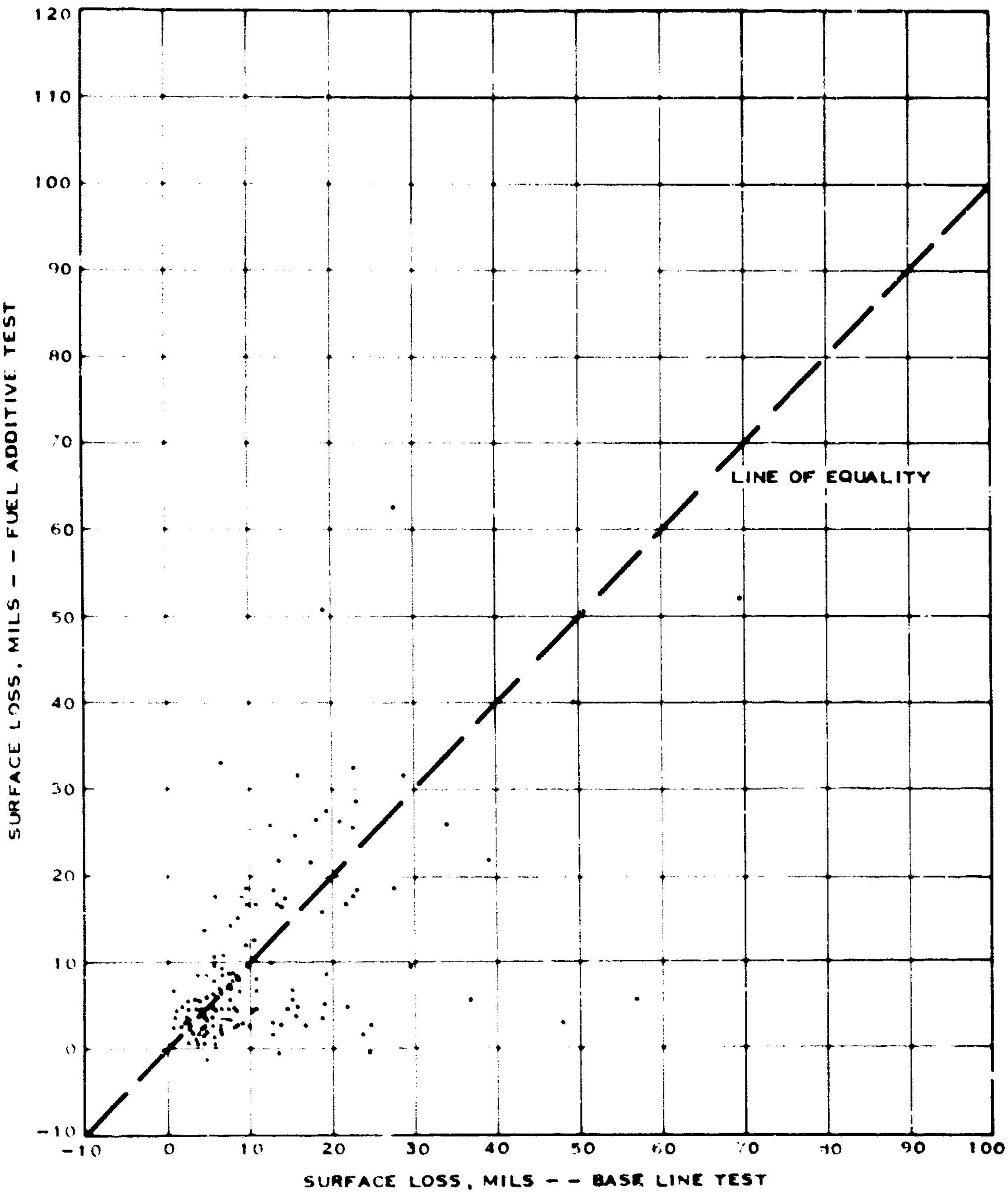


FIGURE 49
EFFECT OF CI-2 ON SURFACE LOSS

For the eight nickel-base superalloys with the MDC-1 coating used in this study, the addition of CI-2 to the fuel either had no statistically significant effect or significantly reduced penetration as measured by surface-loss.

For the eight MDC-9 coated nickel-base superalloys and the four MDC-9 coated cobalt-base superalloys, the addition of 0.1 volume per cent CI-2 to the fuel either had no statistically significant effect or caused a statistically significant reduction in penetration as measured by surface loss.

4.6.4. Durability of Bare Superalloys (Surface-Loss)

Means and comparisons of surface loss for the bare superalloys are shown in Table 32, with the comparisons made on the indicated significant main effects or interactions in the AOV's. A statistically significant superalloy by fuel-additive interaction was indicated for specimens of bare B-1900, Mar M-246, Mar M-200, and IN-100 and comparisons of superalloys are made with the level of additive fixed. In the absence of CI-2 in the fuel the surface-loss for specimens of B-1900 is significantly less than for three superalloys and the surface-loss for IN-100 is less than for Mar M-200. In the presence of 0.1 volume per cent CI-2 in fuel, the surface loss for Mar M-246 is greater than for the other three superalloys which do not differ.

Comparisons of surface-loss for Udimet 700, Udimet 710, IN-738, and Inconel 713C are made with time-of-exposure and level of fuel-additive fixed because of the indicated superalloy by time-of-exposure by fuel-additive interaction. In the absence of CI-2 in the fuel there is no significant difference in surface-loss for specimens of the four superalloys exposed for 10 hours. With 20 hours of exposure the surface-loss for Inconel 713C is greater than for Udimet 710 or IN-738 and with 30 or 40 hours of exposure the surface-loss for Inconel 713C is greater than for Udimet 700 which is greater than for Udimet 710 or IN-738. The surface-loss for specimens exposed in the presence of 0.1 volume per cent CI-2 in the fuel varies with time-of-exposure. Surface-loss for specimens of Inconel 713C was highest or in the highest group at each of the periods of exposure while Udimet 710 was lowest or in the lowest group at 10, 20, and 30 hours and in the highest group at 40 hours.

The AOV of the data for bare WI-52, Mar M-509, and Mar M-302 exposed for 25, 40, 55, and 70 hours indicates a superalloy by fuel-additive interaction and comparisons of superalloys should be made with level of fuel additive fixed while the AOV of the surface-loss data for WI-52, Mar M-509, Mar M-302, and X-40 exposed for 25 and 55 hours indicated a statistically significant main effect of superalloys and comparisons should be made with the data averaged over level of fuel-additive and time-of-exposure. Surface-loss for WI-52 is greater than for Mar M-302 or Mar M-509 in the three metal comparisons in the absence of CI-2 in the fuel and there is no significant difference for surface-loss of the three superalloys in the presence of CI-2. In the comparison of the four superalloys exposed for 25 and 55 hours, the surface-loss for WI-52 is greater than for the other three superalloys.

TABLE 32

COMPARISON OF SURFACE LOSS ON BARE SUPERALLOYS

Mean Surface Loss, mils							
Without CI-2 in Fuel				With 0.1 % CI-2 in Fuel			
5, 10, 15, and 20 hours							
(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)
B-1900	IN-100	MM-246	MM-200	B-1900	IN-100	MM-200	MM-246
7.3	11.1	12.1	14.4	12.8	13.3	14.2	17.8
10 hours							
(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
U-710	U-700	IN-738	I-713C	U-710	U-700	IN-738	I-713C
2.2	2.4	3.5	6.8	0.2	2.4	4.9	10.6
20 hours							
(1)	(1)	(2)	(2)	(1)	(1)	(2)	(2)
IN-738	U-710	U-700	I-713C	U-710	IN-738	U-700	I-713C
1.6	4.4	7.4	11.8	2.3	4.8	11.4	17.6
30 hours							
(1)	(1)	(2)	(2)	(1)	(1)	(2)	(2)
U-710	IN-738	U-700	I-713C	U-710	IN-738	U-700	I-713C
3.0	7.4	14.6	25.7	1.4	14.1	20.7	31.8
40 hours							
(1)	(1)	(2)	(2)	(1)	(2)	(2)	(1)
IN-738	U-710	U-700	I-713C	IN-738	U-700	I-713C	U-710
9.2	15.7	22.6	28.2	17.7	21.4	28.2	31.4
25, 40, 55, and 70 hours							
(7)	(4)	(4)		(7)	(4)	(4)	
MM-509	MM-302	WI-52		MM-509	MM-302	WI-52	
5.4	6.8	13.5		6.1	6.9	9.0	
Without and with CI-2 at 25 and 55 hours							
		(6)	(4)	(4)	(4)		
		MM-509	X-40	MM-302	WI-52		
		5.2	6.1	7.0	10.9		

Notes: Values in parentheses ( ) indicates number of observations.

TSM = 3.0 (6 vs 6)   TSM = 6.4 (1 vs 2)   TSM = 3.7 (4 vs 4)   TSM = 3.4 (4 vs 6)
TSM = 5.2 (2 vs 2)   TSM = 7.4 (1 vs 1)   TSM = 3.3 (4 vs 7)

An overall comparison of the superalloys could not be made because of the different lengths of exposure and location in different rows of the specimen retainer.

4.6.5. Durability of Coated Superalloys (Surface-Loss)

The AOV of the surface-loss data for MDC-1 coated B-1900, Mar M-246, Mar M-200, and IN-100 indicated significant superalloy-coating by time of exposure and superalloy-coating by fuel-additive interactions and comparisons should be made with time-of-exposure and level of fuel-additive fixed and these means and comparisons are shown in Table 33. Where significant differences are shown, the surface-loss for MDC-1 coated IN-100 was greatest and the loss for MDC-1 coated Mar M-200 was the next largest.

No statistically significant effect of superalloys was indicated in the AOV of the surface-loss data for MDC-1 coated Udimet 700, Udimet 710, IN-738, and Inconel 713C and no comparisons are shown.

Of the three AOV's of the surface-loss data for MDC-9 coated B-1900, Mar M-246, Mar M-200, and IN-100 the only statistically significant effect that involved superalloy-coating systems was a main effect for the superalloy-coating systems exposed for 80 hours. Means and comparisons of the data are presented in Table 34 and show that surface-loss for MDC-9 coated IN-100 is greater than for the other three superalloy-coating systems.

No statistically significant difference in surface-loss for MDC-9 coated Udimet 700 and Udimet 710 was indicated.

A statistically significant superalloy-coating system by fuel-additive interaction was indicated by the AOV of the surface-loss data for MDC-9 coated Inconel 713C and IN-738 and means and comparisons are shown in Table 34 with the level of fuel-additive fixed. In the absence of CI-2 in the fuel the surface-loss for MDC-9 coated Inconel 713C was greater than for MDC-9 coated IN-738 while there was no significant difference in surface-loss for the two superalloy-coating systems in the presence of CI-2 in the fuel.

An examination of the surface-loss data for MDC-9 coated WI-52, Mar M-509, Mar M-302, and X-40 indicated no statistically significant effect of superalloys.

Specimens of bare and MDC-1 coated Udimet 700, Udimet 710, IN-738, and Inconel 713C were exposed in the same row in the specimen retainer for the same lengths of time and provide an evaluation of the effect of the coating on durability of the materials. An AOV of the surface-loss data indicated a statistically significant coating by superalloy and coating by fuel-additive interactions and comparisons of the coating should be made with the superalloy and level of fuel-additive fixed. Means and comparisons of the data are shown in Table 35. In the absence of CI-2 in the fuel the MDC-1 coating reduced the surface-loss for Inconel 713C and had no significant effect on the other three superalloys. With 0.1 volume per cent CI-2 in the fuel the MDC-1 coating reduced surface-loss for Inconel 713C, Udimet 700, and Udimet 710 specimens but had no significant effect on IN-738 specimens.

TABLE 33

COMPARISON OF SURFACE LOSS ON MDC-1 COATED SUPERALLOYS

Mean Surface Loss, mils							
Without CI-2 in Fuel				With 0.1 % CI-2 in Fuel			
40 hours							
MM-246	MM-200	IN-100	B-1900	MM-246	MM-200	IN-100	B-1900
6.9	9.0	12.8	18.5	1.6	3.0	3.0	3.4
50 hours							
MM-246	B-1900	MM-200	IN-100	MM-200	B-1900	MM-246	IN-100
3.3	3.4	13.6	27.4	-0.3	3.2	5.4	18.4
60 hours							
MM-246	B-1900	MM-200	IN-100	MM-200	B-1900	MM-246	IN-100
5.5	9.9	24.9	49.6	-0.6	2.4	3.2	40.0
80 hours							
MM-246	B-1900	MM-200	IN-100	MM-200	MM-246	B-1900	IN-100
10.2	19.0	47.9	69.6	3.0	4.6	5.0	52.0

Notes:

All means single observations.

TSM = 19.8 (1 vs 1)

TABLE 34

COMPARISON OF SURFACE LOSS ON MDC-9 COATED SUPERALLOYS

Mean Surface Loss, mils

Without CI-2 in Fuel		With 0.1 % CI-2 in Fuel	
165 hours			
(2) IN-738	(2) I-713C	(2) I-713C	(2) IN-738
18.2	46.5	5.3	10.6

Without and with CI-2 at 80 hours

(2) MM-246	(2) B-1900	(2) MM-200	(2) IN-100
2.2	3.0	3.3	30.5

Notes:

Values in parentheses ( ) indicates number of observations.

TSM = 14.0 (2 vs 2)

TABLE 35

COMPARISON OF SURFACE LOSS ON BARE VS MDC-1 COATED SUPERALLOYS

Superalloy	Comparison of Surface Loss at 40 Hours: Mean, mils — Bare	Mean, mils — MDC-1	Difference, mils — Bare - MDC-1
	Without CI-2 in Fuel		
Inco 713C	32.2 (2)	3.6 (1)	28.6 *
Udimet 700	22.6 (2)	6.2 (1)	16.4
IN-738	9.2 (1)	5.3 (1)	3.9
Udimet 710	15.7 (1)	6.1 (1)	9.6
	With 0.1 % CI-2 in Fuel		
Inco 713C	28.2 (2)	0.8 (1)	27.4 *
Udimet 700	21.4 (2)	0.6 (1)	20.8 *
IN-738	17.7 (1)	3.8 (1)	13.9
Udimet 710	31.4 (1)	4.8 (1)	26.6 *

Notes:

Values in parentheses ( ) = number of observations in a mean.

TSM = 17.2 (2 vs 1)

TSM = 19.8 (1 vs 1)

Asterisk (*) indicates a significant effect at 95 per cent confidence level.

Specimens of B-1900, Mar M-246, Mar M-200, and IN-100 with Misco MDC-1 and MDC-9 coatings were exposed for the same lengths of time in the same row of the specimen retainer and provide a comparison of the relative durability of the coatings on these four superalloys. The AOV of the surface loss data indicated statistically significant interactions of coatings by superalloys and coatings by fuel-additives and comparisons of the effect of coatings on surface-loss should be made with the superalloys and the level of fuel-additive fixed. Means and comparisons of the data are shown in Table 36. In the absence of CI-2 in the fuel, MDC-9 coating reduced the surface-loss for Mar M-200 and IN-100 and was not significantly different from the MDC-1 coating on B-1900 and Mar M-246. In the presence of 0.1 volume per cent CI-2 in the fuel the surface-loss with MDC-9 coated IN-100 was significantly less than with the MDC-1 coating and there was no significant difference in surface-loss between MDC-1 and MDC-9 on B-1900, Mar M-246, and Mar M-200.

4.6.6. Effect of Manganese Additive on Maximum Penetration of Bare Superalloys

An AOV of the maximum penetration data for bare B-1900, Mar M-246, Mar M-200, and IN-100 specimens indicated that the data should be examined for significant main effects of additives, superalloys, and time-of-exposure; however, when these comparisons were made the estimated effect of additives was not found to be significant. This contradiction led to a closer examination of the data whereby the actual members for the effect of additives could be compared. The results of this examination (Table 37) indicate that for three of the superalloys, the estimated effects of the additive are -0.2, 0.8, and 1.5. For the Mar M-246, the effect of the additive is estimated to be 7.6 which is statistically significant. This implies a superalloy by fuel-additive interaction. The failure of this interaction to show up in the AOV, is due to the equal weighting of the four estimated additive effects. The three small effects are off-setting the one large effect and the "average" as estimated by the superalloy by fuel-additive interaction is not large enough to be detected.

The AOV of the maximum penetration data for bare Udimet 700, Udimet 710, IN-738, and Inconel 713C indicates a significant main effect of fuel-additive and means and comparisons are shown in Table 37. These data indicate that the presence of 0.1 volume per cent CI-2 in the fuel significantly increased the maximum penetration for these four superalloys.

Means and comparisons of the maximum penetration data for WI-52, Mar M-509, and Mar M-302 exposed for 25, 40, 55, and 70 hours are presented in Table 37 and indicate that the presence of CI-2 in the fuel significantly decreases the maximum penetration for specimens of WI-52 and had no significant effect on Mar M-509, and Mar M-302. The means and comparison of the maximum penetration data for X-40 exposed for 25, 55, 85, and 115 hours show that the presence of CI-2 in the fuel significantly increased maximum penetration.

For the twelve bare superalloys tested in this program, the addition of 0.1 volume per cent CI-2 to the fuel either had no significant effect, or it caused a statistically significant increase in maximum

TABLE 36

COMPARISON OF SURFACE LOSS OF MDC-1 VS MDC-9 COATED SUPERALLOYS

Superalloy	Comparison of Surface Loss at 80 hours: Mean, mils MDC-1	Mean, mils MDC-9	Difference, mils MDC-1 — MDC-9
	Without CI-2 in Fuel		
B-1900	19.0 (1)	2.5 (1)	16.5
Mar M-246	10.2 (1)	4.2 (1)	6.0
Mar M-200	47.9 (1)	5.5 (1)	42.4 *
IN-100	69.6 (1)	39.2 (1)	30.4 *
	With 0.1 % CI-2 in Fuel		
B-1900	5.0 (1)	3.4 (1)	1.6
Mar M-246	4.6 (1)	0.2 (1)	4.4
Mar M-200	3.0 (1)	1.1 (1)	1.9
IN-100	52.0 (1)	21.8 (1)	30.2 *

Notes:

Values in parentheses ( ) = number of observations in a mean.

TSM = 19.8 (1 vs 1)

Asterisk (*) indicates a significant effect at 95 per cent confidence level.

TABLE 37

EFFECT OF CI-2 ON MAXIMUM PENETRATION OF BARE SUPERALLOYS

Superalloy	Comparison of Maximum Penetration at 5, 10, 15, and 20 hours: Means, mils A_1	A_0	Difference, mils $A_1 - A_0$
B-1900	16.6 (6)	15.8 (6)	0.8
Mar M-246	25.8 (6)	18.2 (6)	7.6 *
Mar M-200	22.8 (6)	23.0 (6)	-0.2
IN-100	21.0 (6)	19.5 (6)	1.5

Superalloys	Comparison of Maximum Penetration at 10, 20, 30 and 40 hours: Means, mils A_1	A_0	Difference, mils $A_1 - A_0$
Inco 713C Udimet 700 IN-738 Udimet 710	28.3 (24)	21.7 (24)	6.6 *

	Comparison of Maximum Penetration at 25, 40, 55 and 70 hours: Means, mils A_1	A_0	Difference, mils $A_1 - A_0$
WI-52	17.0 (4)	25.0 (4)	-8.0 *
Mar M-509	16.0 (7)	14.5 (7)	1.5
Mar M-302	10.4 (4)	13.8 (4)	-3.4
X-40 (a)	37.0 (4)	29.1 (4)	7.9 *

Notes:

A_0 = Test fuel without CI-2 additive.

A_1 = Test vuel with 0.1 volume per cent CI-2 additive.

Values in parentheses ( ) = number of observations in a mean.

TSM = 5.7 (6 vs 6)
TSM = 2.9 (24 vs 24)
TSM = 7.0 (4 vs 4)
TSM = 5.3 (7 vs 7)

Asterisk (*) indicates a significant effect at 95 per cent confidence level.

(a) Specimens exposed for 25, 55, 85, and 115 hours.

penetration. The effect of the additive on WI-52 was an exception and the addition of CI-2 to the fuel reduced maximum penetration.

4.6.7. Effect of Manganese Additive on Maximum Penetration of Coated Superalloys

The AOV of the maximum penetration data for MDC-1 coated B-1900, Mar M-246, Mar M-200, and IN-100 indicated a statistically significant main effect of fuel-additive the means of the data averaged over superalloys and time-of-exposure are shown in Table 38. This comparison indicates that the presence of 0.1 volume per cent CI-2 in the fuel significantly decreased maximum penetration.

A statistically significant main effect of additives on maximum penetration is also indicated by the AOV of the data for MDC-1 coated Udimet 700, Udimet 710, IN-738, and Inconel 713C and the means in Table 38 show that the presence of CI-2 in the fuel significantly decreases maximum penetration for these four superalloy-coating systems.

AOV's were made of the various combinations of maximum penetration data for MDC-9 coated B-1900, Mar M-246, Mar M-200, and IN-100. The only significant effect of additive-in-fuel was indicated from an AOV of data for MDC-9 coated IN-100 exposed for various periods of time and the means and comparisons in Table 39 indicate that the presence of CI-2 in the fuel reduces maximum penetration.

No statistically significant effect of additive-in-fuel on maximum penetration was indicated for specimens of MDC-9 coated Udimet 700 and Udimet 710 exposed for 75 and 90 hours.

The AOV of the maximum penetration data for specimens of MDC-9 coated Inconel 713C and IN-738 exposed for 165 hours indicated a significant superalloy-coating system by fuel-additive interaction and means and comparisons of the data are presented in Table 39. These data show that the presence of CI-2 in the fuel significantly reduced maximum penetration for MDC-9 coated Inconel 713C and had no significant effect on the other superalloy-coating system.

No significant additive effect was indicated by the AOV of the maximum penetration data for MDC-9 coated WI-52, Mar M-509, Mar M-302, and X-40.

The maximum penetration measurements for individual specimens exposed without and with 0.1 volume per cent CI-2 in the fuel is shown in Figure 50 and indicates the variability of the data.

For the eight MDC-1 coated nickel-base superalloys tested in this program the presence of CI-2 in the fuel significantly reduced attack as measured by maximum penetration. For the twelve MDC-9 coated superalloys, the addition of CI-2 to the fuel either had no statistically significant effect of significantly reduced maximum penetration.

TABLE 38

EFFECT OF CI-2 ON MAXIMUM PENETRATION OF MDC-1 COATED SUPERALLOYS

MDC-1 Coated Superalloy	Comparison of Maximum Penetration at 40, 50, 60, and 80 hours		
	Mean, mils		Difference, mils
	A_1	A_0	$A_1 - A_0$
B-1900 Mar M-246 Mar M-200 IN-100	18.1 (16)	36.2 (16)	-18.1 *
Udimet 700 Udimet 710 IN-738 Inco 713C	11.4 (19)	26.7 (19)	-15.3 *

Notes:

A_0 = Test fuel without additive.

A_1 = Test fuel with 0.1 volume per cent CI-2 additive.

Value in parenthese ( ) = number of observations in a mean.

TSM = 10.6 (16 vs 16)
TSM = 9.8 (19 vs 19)

Asterisk (*) indicates a significant effect at 95 per cent confidence level.

TABLE 39

EFFECT OF CI-2 ON MAXIMUM PENETRATION OF MDC-9 COATED SUPERALLOYS

MDC-9 Coated Superalloy	Comparison of Maximum Penetration at Test Hours: Mean, mils A_1	Mean, mils A_0	Difference, mils $A_1 - A_0$
IN-100 (a)	13.6 (4)	39.4 (4)	-25.8 *
Inco 713C (b)	14.4 (2)	65.4 (2)	-51.0 *
IN-738 (b)	32.2 (2)	40.4 (2)	-8.2

Notes:

A_0 = Test fuel without additive.

A_1 = Test fuel with 0.1 volume per cent CI-2 additive.

Value in parentheses ( ) = number of observations in a mean.

TSM = 21.2 (4 vs 4)
TSM = 30.0 (2 vs 2)

Asterisk (*) indicates a significant effect at 95 per cent confidence level.

(a) Specimens exposed for 45, 55, 65 and 80 hours.

(b) Specimens exposed for 165 hours.

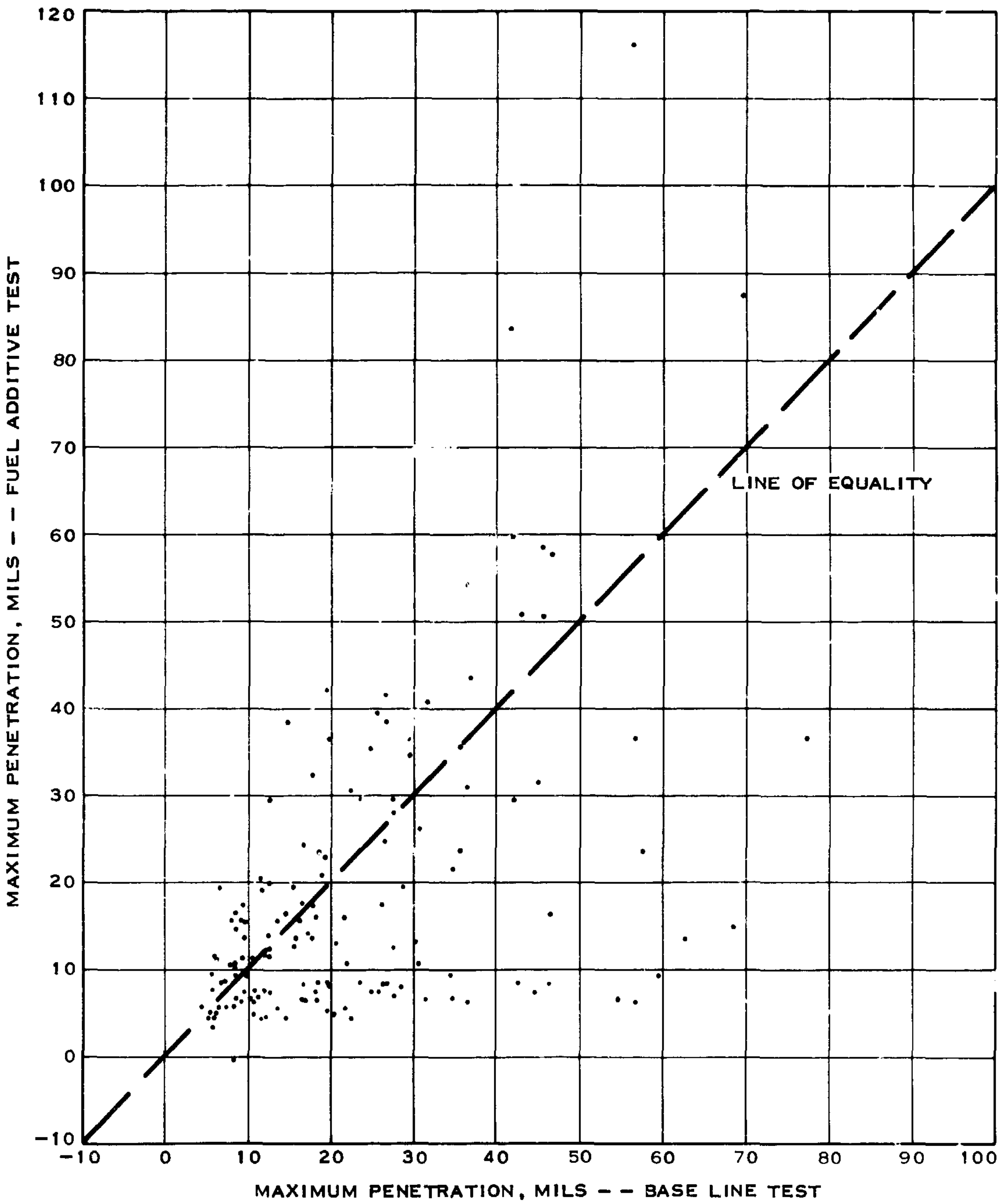


FIGURE 50
EFFECT OF CI–2 ON MAXIMUM PENETRATION

4.6.8. Durability of Bare Superalloys (Maximum Penetration)

Comparisons of the durability of the bare superalloys can be made for those superalloys exposed for the same lengths of time in the same row of the specimen retainer and the comparisons of the twelve bare superalloys in the program are divided into three groups.

The AOV of the maximum-penetration data for bare B-1900, Mar M-246, Mar M-200, and IN-100 indicated that comparisons are to be made with the level of fuel-additive fixed (Table 40). These data show that maximum penetration for B-1900 specimens exposed in the absence of CI-2 in fuel had significantly less maximum penetration than for specimens of Mar M-200, and in the presence of 0.1 volume per cent CI-2 in the fuel the maximum penetration for specimens of B-1900 was significantly less than for Mar M-246.

The AOV of the maximum penetration data for bare Udimet 700, Udimet 710, IN-738, and Inconel 713C indicated that comparisons should be made of the data averaged over level of fuel-additive but with time-of-exposure fixed. Means and comparisons of the maximum penetration for these four superalloys are shown in Table 40. The relative levels of attack on the four superalloys vary with time-of-exposure; however, where statistically differences are shown, the maximum penetration of Inconel 713C is in the highest group.

The AOV's of the maximum penetration data for bare Mar M-302, Mar M-509, X-40, and WI-52 indicated that data for the various combinations can be made with the data averaged over the levels of fuel-additive. Means and comparisons of the data are presented in Table 40. Where statistically significant differences are shown, maximum penetration for Mar M-302 and Mar M-509 is less than for WI-52 and maximum penetration for WI-52 is less than for X-40.

Statistically significant interactions negate any overall conclusion regarding comparisons of bare superalloys based on maximum penetration.

4.6.9. Durability of Coated Superalloys (Maximum Penetration)

The AOV for the maximum penetration data for Misco MDC-1 coated B-1900, Mar M-246, Mar M-200, and IN-100 indicated a statistically significant superalloy-coating system by time-of-exposure interaction and comparisons of the superalloy-coating systems should be made with time-of-exposure fixed. Means and comparisons of the data are shown in Table 41 and indicate that where statistically significant differences in maximum penetration occur, the maximum penetration for MDC-1 coated IN-100 is greater than for the other three superalloy-coating systems. No significant difference in maximum penetration is shown for MDC-1 coated Mar M-246, Mar M-200 or B-1900.

No statistically significant main effect or interaction involving superalloy-coating systems were indicated by the AOV of the maximum penetration data for MDC-1 coated Udimet 700, Udimet 710, IN-738, or Inconel 713C, which indicates no significant difference in maximum penetration for these four superalloy-coating systems.

TABLE 40

COMPARISON OF MAXIMUM PENETRATION ON BARE SUPERALLOYS

Mean Maximum Penetration, mils

Without CI-2 in Fuel				With 0.1 % CI-2 in Fuel			

5, 10, 15, and 20 hours

(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)
B-1900	MM-246	IN-100	MM-200	B-1900	IN-100	MM-200	MM-246
15.8	18.2	19.5	23.0	16.6	21.0	22.8	25.8

Without and with CI-2

10 hours

(4)	(2)	(2)	(4)
U-700	U-710	IN-738	I-713C
9.1	12.3	12.4	16.8

20 hours

(2)	(2)	(4)	(4)
U-710	IN-738	U-700	I-713C
15.9	16.3	20.2	21.5

30 hours

(2)	(2)	(4)	(4)
U-710	IN-738	U-700	I-713C
14.6	25.0	29.6	36.4

40 hours

(2)	(4)	(2)	(4)
IN-738	U-700	U-710	I-713C
28.0	34.3	45.4	47.6

25, 40, 55, and 70 hours

(8)	(14)	(8)
MM-302	MM-509	WI-52
12.2	15.2	21.0

25 hours

(2)	(2)	(2)	(2)
MM-509	MM-302	X-40	WI-52
8.2	9.4	11.4	17.4

TABLE 40 (Cont'd)

Mean Maximum Penetration, mils	
Without CI-2 in Fuel	With 0.1 % CI-2 in Fuel

Without and With CI-2

(2) MM-302	(4) MM-509	(2) WI-52	(2) X-40
9.5	12.7	21.5	32.2

20 hours

(2) MM-302	(2) WI-52	(2) X-40
4.3	12.0	14.0

Notes:

Values in parentheses ( ) indicate number of observations.

TSM = 5.7 (6 vs 6)
TSM = 7.0 (4 vs 4)
TSM = 9.9 (2 vs 2)
TSM = 8.6 (4 vs 2)
TSM = 5.0 (8 vs 8)
TSM = 4.4 (14 vs 8)

TABLE 41

COMPARISON OF MAXIMUM PENETRATION ON MDC-1 COATED SUPERALLOYS

Mean Maximum Penetration, mils

Without and With CI-2

40 hours

MM-200	MM-246	IN-100	B-1900
12.4	16.2	17.3	31.3

50 hours

B-1900	MM-246	MM-200	IN-100
8.4	12.6	16.6	46.6

60 hours

MM-246	B-1900	MM-200	IN-100
12.8	13.6	21.2	78.6

80 hours

MM-246	B-1900	MM-200	IN-100
14.2	18.2	34.2	80.5

Notes:

All values means of two observations.

TSM = 30.0 (2 vs 2)

On the basis of the AOV's of the three groups of MDC-9 coated superalloys the means and comparisons for evaluating the indicated significant effects of superalloy-coating systems on maximum penetration are presented in Table 42. A significant interaction of superalloy-coating system by additive-in-fuel was indicated for the maximum penetration data for MDC-9 coated IN-738 and Inconel 713C and comparisons are made with level of additive fixed. No significant difference is shown between the two superalloy-coating systems for maximum penetration at either level of additive-in-fuel. The interaction was the result of differences in fuel effects on the superalloy-coating systems.

The AOV of the maximum penetration data for MDC-9 coated B-1900, Mar M-246, Mar M-200, and IN-100 indicated a statistically significant main effect of superalloy-coating systems and the comparisons in Table 42 show that the maximum penetration with MDC-9 coated IN-100 is significantly greater than with the other three superalloy-coating systems.

Specimens of bare and MDC-1 coated Udimet 700, Udimet 710, IN-738, and Inconel 713C were exposed for the same periods of time in the same row of the specimen retainer and provide an evaluation of the effect of the coating of the materials on maximum penetration. An AOV of the maximum penetration data for these four superalloys and superalloy-coating systems indicated a statistically significant main effect of coating and comparisons should be made of means of the data averaged over superalloys and additive-in-fuel. The mean value for maximum penetration for the bare superalloys is 45.5 mils and for the MDC-1 coated superalloys the mean is 13.6 mils. The difference of 31.9 mils is greater than the calculated TSM of 11.0 mils and indicates that the MDC-1 coating significantly reduced maximum penetration for these four superalloys.

Specimens of B-1900, Mar M-246, Mar M-200, and IN-100 with Misco MDC-1 and MDC-9 coatings were exposed for the same lengths of time in the same row of the specimen retainer and provide an evaluation of the relative durability of the coatings on these four superalloys. The AOV of the maximum penetration data for these superalloy-coating systems indicated a statistically significant main effect of coatings and comparisons should be made of the data averaged over superalloys and additive-in-fuel. The mean value for maximum penetration of the four MDC-1 coated superalloys was 36.8 mils and for the MDC-9 coated superalloy was 18.9 mils. The difference of 17.9 mils is larger than the calculated TSM of 15.0 mils and indicates that maximum penetration with a MDC-9 coating on these four superalloys is significantly less than with a MDC-1 coating on the same superalloys.

TABLE 42

COMPARISON OF MAXIMUM PENETRATION ON MDC-9 COATED SUPERALLOYS

Mean Maximum Penetration, mils

Without CI-2 in Fuel		With 0.1 % CI-2 in Fuel	
165 hours			
(2) IN-738	(2) I-713C	(2) I-713C	(2) IN-738
40.4	65.4	14.4	32.2

With and Without CI-2 at 80 hours

(2) B-1900	(2) MM-246	(2) MM-200	(2) IN-100
5.2	5.2	8.3	57.0

Notes:

Values in parenthses ( ) indicate number of observations.

TSM = 30.0 (2 vs 2)

4.7. Comparison of Methods for Evaluation of Hot Corrosion

In this report three methods (weight-loss, surface-loss and maximun penetration) have been used to evaluate the effect of CI-2 in fuel on hot corrosion of turbine-blade materials, and to evaluate, where possible, the relative durability of superalloys, superalloy-coating systems, and coatings.

Graphical comparisons have been made of the extent of damage measured by these methods by plotting surface-loss against weight-loss,and maximum penetration against weight-loss. In addition, a theoretical relationship has been calculated, which is based on uniform attack of the stem of the specimen and an average density for the superalloys and superalloy-coating systems in the program. The line representing this relationship has been included on each graph for reference.

The relationship between surface-loss (mils) and weight-loss (mg/cm^2) for the base line and fuel-additive tests are shown in Figures 51 and 52 respectively. The points on the figures represent the data for each specimen exposed in the test. In general the points fall along the line of the theoretical relationship. This indicates that surface-loss and weight-loss techniques determine essentially the same extent of damage to the specimens.

The relationships between maximum penetration (mils) and weight-loss (mg/cm^2) for the base line and fuel-additive test are shown in Figures 53 and 54 respectively. The data points represent values for each specimen exposed in each test. There is more scatter of the maximum penetration data than of the surface-loss data in the previous figures and the level of attack is more severe than for the surface-loss data; however, the general trends for surface-loss and maximum penetration are about the same.

A summary of the statistically significant effects of CI-2 in fuel on hot corrosion of the turbine-blade materials, as indicated by each of the three methods of evaluation, is shown in Table 43. An examination of the effects show instances where only two of the three methods agree and the methods that agree may vary from one superalloy or superalloy-coating system to another. However, in no case is there a reversal in the direction of a significant effect for a superalloy or superalloy-coating system. On the basis of these comparisons, any one of the methods could have been used to determine that CI-2 in the fuel can have an effect on the hot corrosion of superalloys. In general, these results indicate that for the turbine-blade material in this program, 0.1 volume per cent CI-2 in JP-5 fuel has either no effect or increases hot corrosion of bare superalloys, and either has no effect or decreases hot corrosion of coated superalloys.

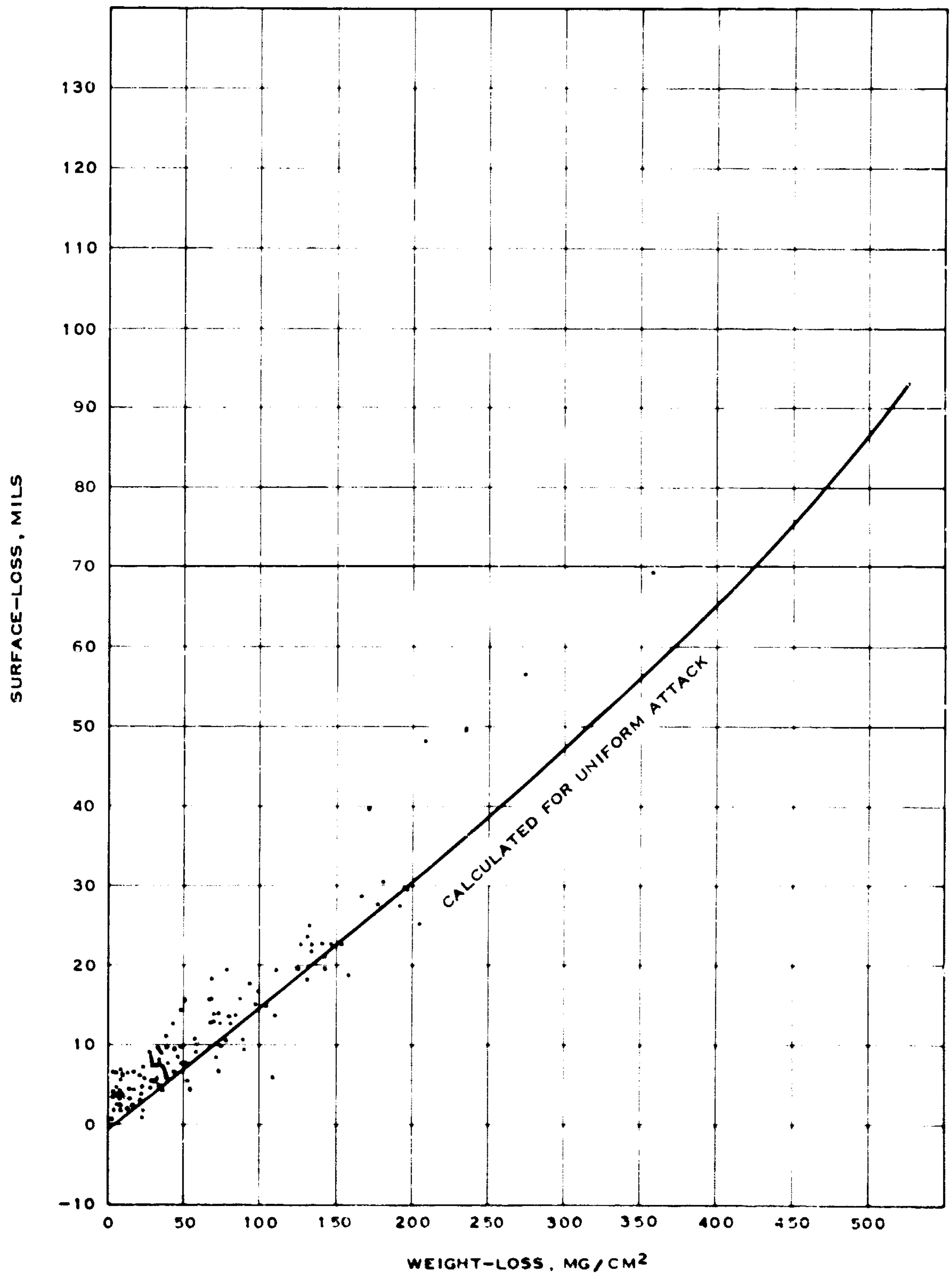


FIGURE 51
RELATIONSHIP BETWEEN SURFACE-LOSS AND WEIGHT-LOSS
FOR BASE LINE TEST

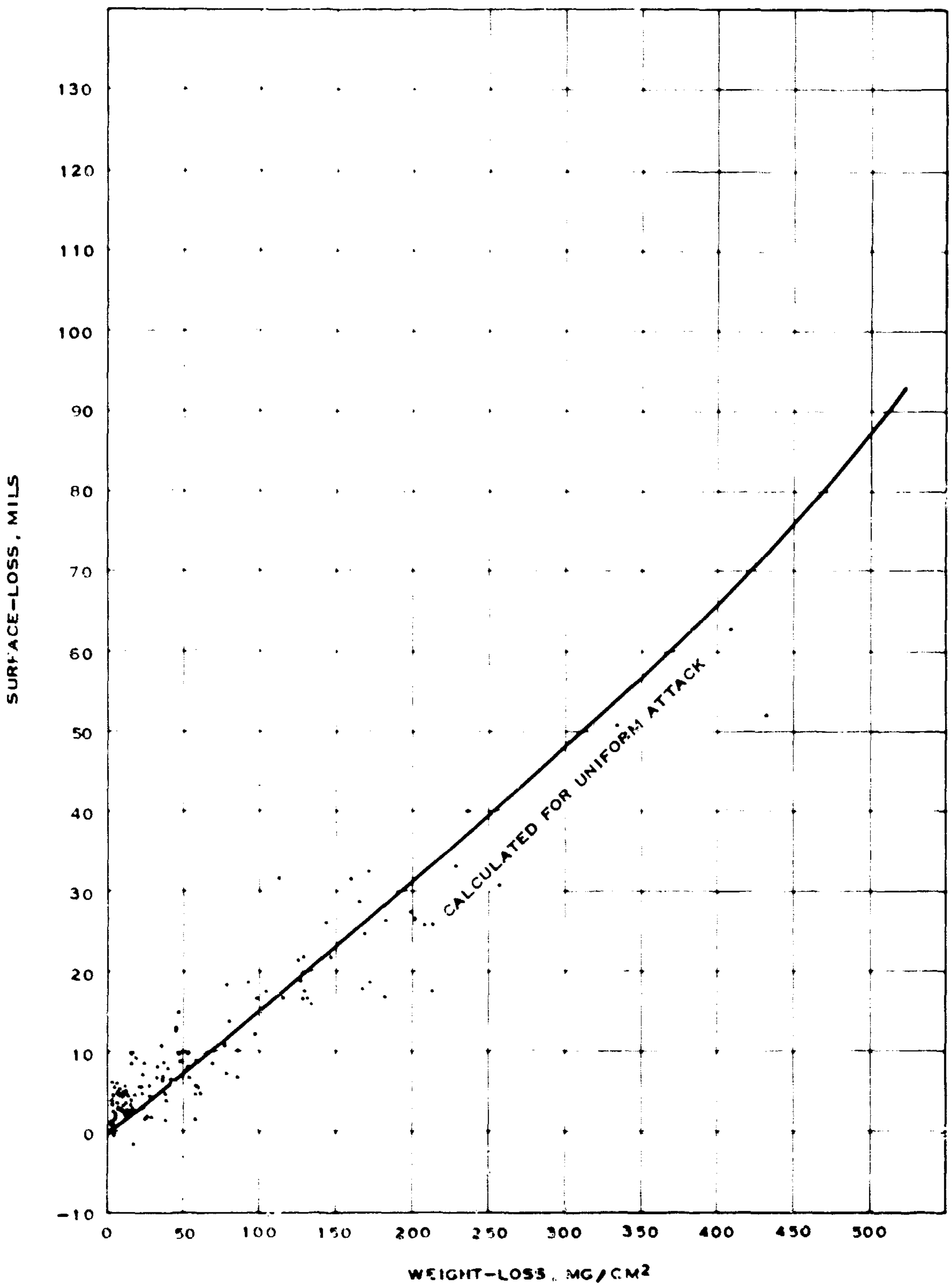


FIGURE 52
RELATIONSHIP BETWEEN SURFACE-LOSS AND WEIGHT-LOSS
FOR FUEL-ADDITIVE TEST

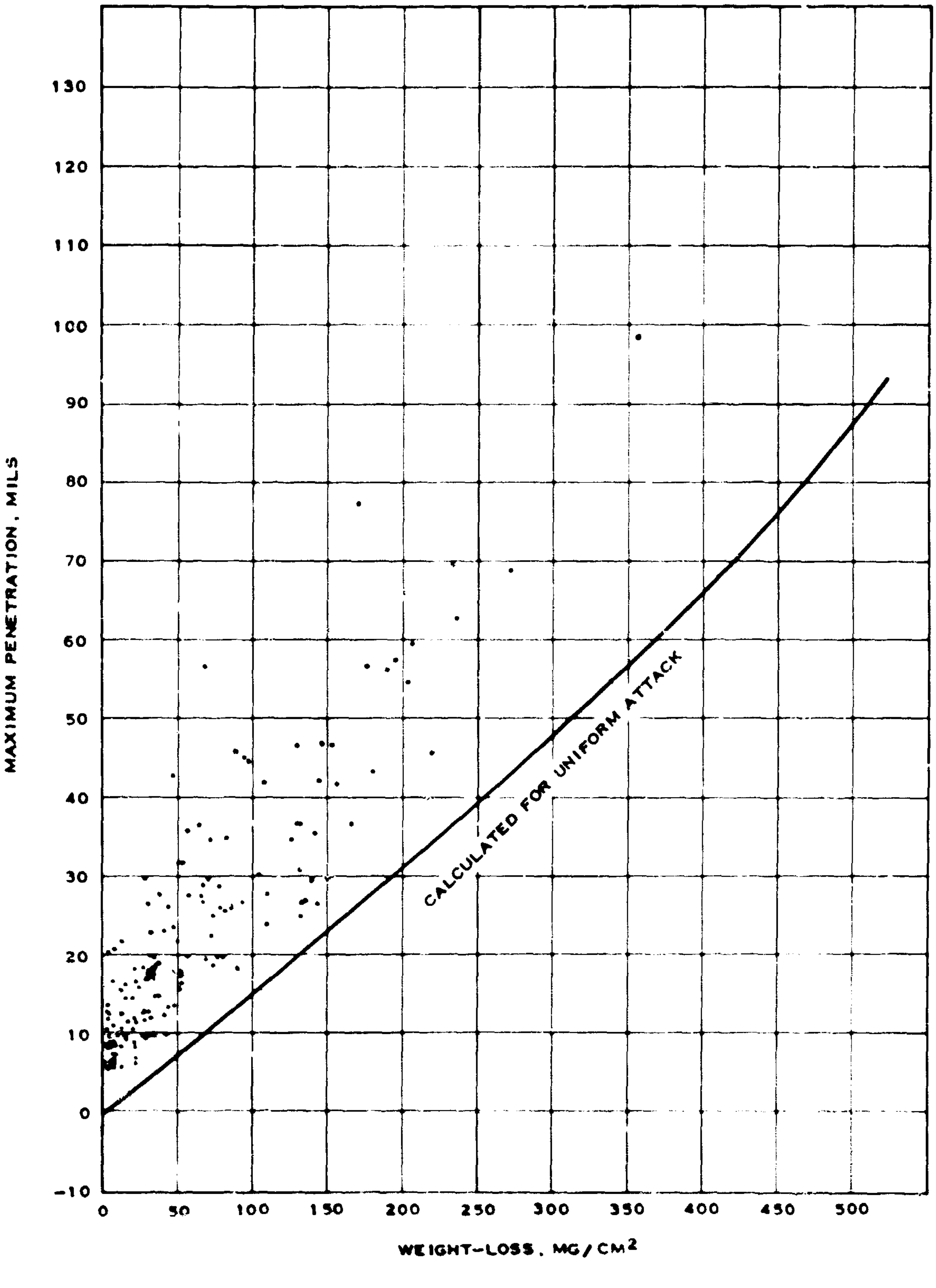


FIGURE 53
RELATIONSHIP BETWEEN MAXIMUM PENETRATION AND WEIGHT-LOSS
FOR BASE LINE TEST

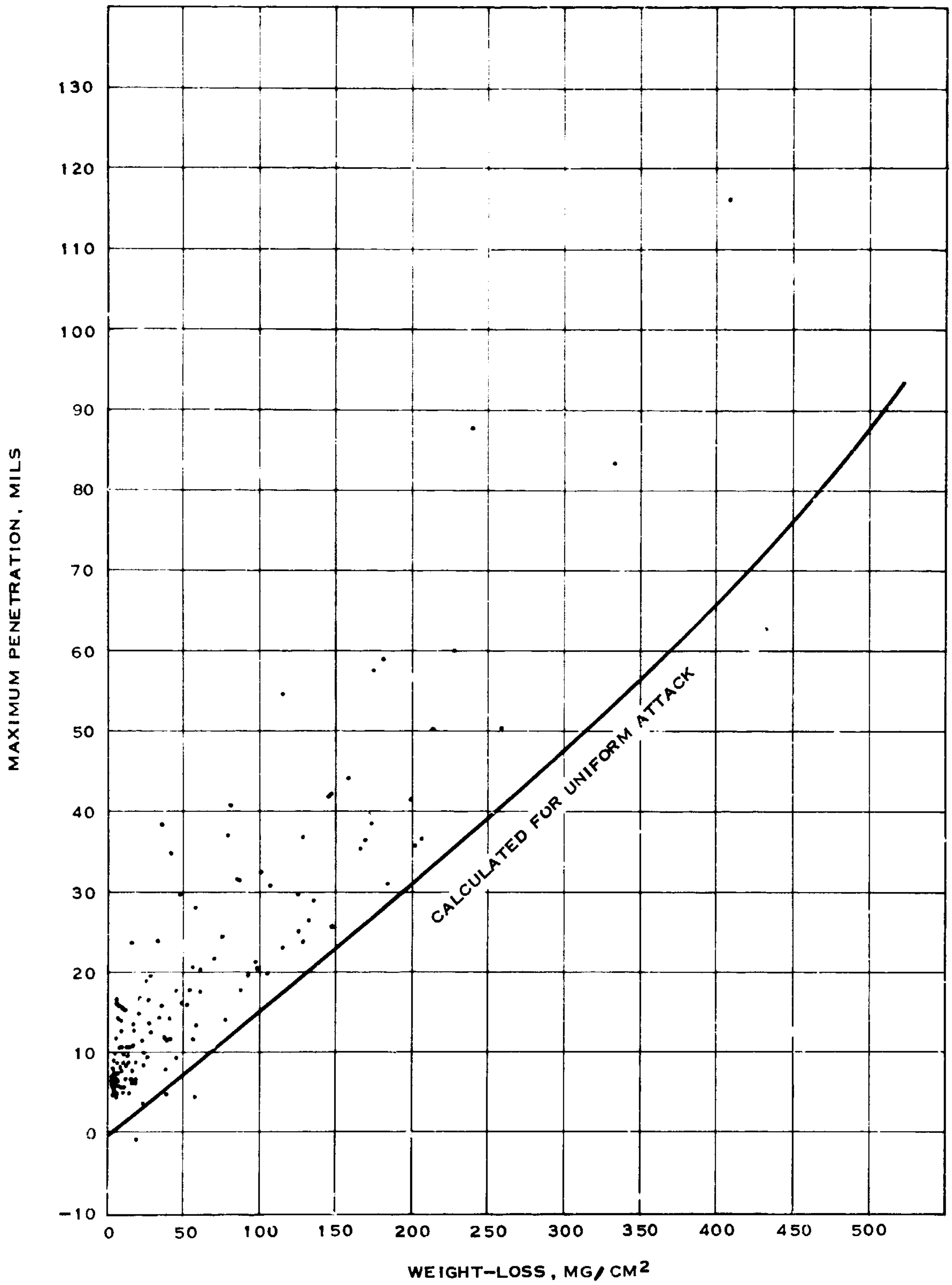


FIGURE 54
RELATIONSHIP BETWEEN MAXIMUM PENETRATION AND WEIGHT-LOSS
FOR FUEL-ADDITIVE TEST

TABLE 43

COMPARISON OF METHODS FOR EVALUATION OF EFFECT OF CI-2 ADDITION ON HOT CORROSION OF TURBINE BLADE MATERIALS

	Estimated Effect of CI-2 (Fuel Additive minus Base Line Test)								
	Bare			MDC-1 Coated			MDC-9 Coated		
Superalloy	Weight Loss, log mg/cm^2	Surf. Loss, mils	Max. Pen., mils	Weight Loss, log mg/cm^2	Surf. Loss, mils	Max. Pen., mils	Weight Loss, log mg/cm^2	Surf. Loss, mils	Max. Pen., mils
B-1900	+	+ & 0	0	-	0	-	0	0	0
Mar M-246	+	+ & 0	+	-	0	-	0	0	0
Mar M-200	+	0	0	-	-	-	0	0	0
IN-100	+	+ & 0	0	0	-	-	- & 0	-	-
Inconel 713C	0	+ & 0	+	-	-	-	-	-	-
Udimet 700	+	+ & 0	+	-	-	-	0	0	0
~~IN-738~~	+	+ & 0	+	-	-	-	0	0	0
Udimet 710	0	+ & 0	+	-	-	-	0	0	0
WI-52	0	-	0		Not Tested		+	0	0
Mar M-509	0	0	0		Not Tested		0	0	0
Mar M-302	0	0	0		Not Tested		0	0	0
X-40	0	+ & 0	+		Not Tested		0	0	0

Notes:

0 = No significant effect of CI-2 on hot corrosion.

+ = Significant increase in hot corrosion with CI-2.

- = Signficiant decrease in hot corrosion with CI-2.

+ & 0 = Signficiant increase in hot corrosion with CI-2 at some times of exposure and no effect at other times of exposure.

- & 0 = Significant decrease in hot corrosion with CI-2 at some times of exposure and no effect at other times of exposure.

5. FUTURE WORK

With the issuance of this report, research efforts under Navy Contract N00156-67-C-2351 on "Smoke Abatement in Gas-Turbines" are concluded. No further work is planned in this area of fuels research.

6. ACKNOWLEDGEMENTS

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Deposit Analysis by M. J. Dreiling, J. E. Puckett, and R. C. Ramsey.

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8. APPENDIX 1

(Test Equipment)

8.1. Test Facility

Phillips research facility for testing jet fuel, pictured in part in Figure 55 has been described in detail by Fromm (16).

Air is supplied by rotary Fuller compressors and filtered by a Selas Vape-Sorber, both of which can be seen in the foreground. This air is preheated just before it enters the burner by a Thermal Research heat exchanger. Both fuel and sea water are supplied by nitrogen pressurization of their respective tanks. A portion of the metering and automatic control equipment can be seen in Figure 56.

The burners operate with air-flow rates up to 2.0 lb/sec at inlet-air pressure up to 240 psi and inlet-air temperature up to 1400 F.

8.2. Phillips 2-Inch Combustor

A scale diagram of the 2-inch combustor used in this study is shown in Figure 57. Design details of the combustor are presented in Table 44. Basically, it embodies the principal features of combustors used in modern aircraft-turbine engines. It is a straight-through can-type, combustor with fuel atomization by a single, simplex-type nozzle. The combustor liner is fabricated from 2-inch Schedule 40, Inconel pipe, with added internal deflector skirts for film cooling of surfaces exposed to the flame.

8.3. Phillips Turbine Simulator

The Phillips Turbine Simulator is shown in Figure 58. A scale diagram of the equipment is shown in Figure 59. Its design permits easy access to the fuel nozzle, combustor liner, test specimens, etc. The combustor installation is disassembled, inspected, and reconditioned after every shutdown.

Four chromel-alumel thermocouples are mounted at 90 degree intervals, with the tips 3/8-inch upstream from the centers of the first row of specimens, for measurement of gas temperature. The thermocouples are housed in 1/4-inch diameter Inconel sheaths for protection.

A look-box, Figure 58, permits observation of the test specimens during operation to obtain temperature measurements with an optical pyrometer.

Sea water is injected into the quench zone of the combustor, as indicated in Figure 59, rather than upstream of the combustor or into the primary-combustion zone. Injection into the quench zone avoids a severe corrosion problem with the combustor liner, and also insures exposure of test specimens to the desired sea-salt concentration. The sea water is divided into two metered portions and introduced through opposing jets to obtain uniform distribution of sea salt in air by impingment of the jet streams.

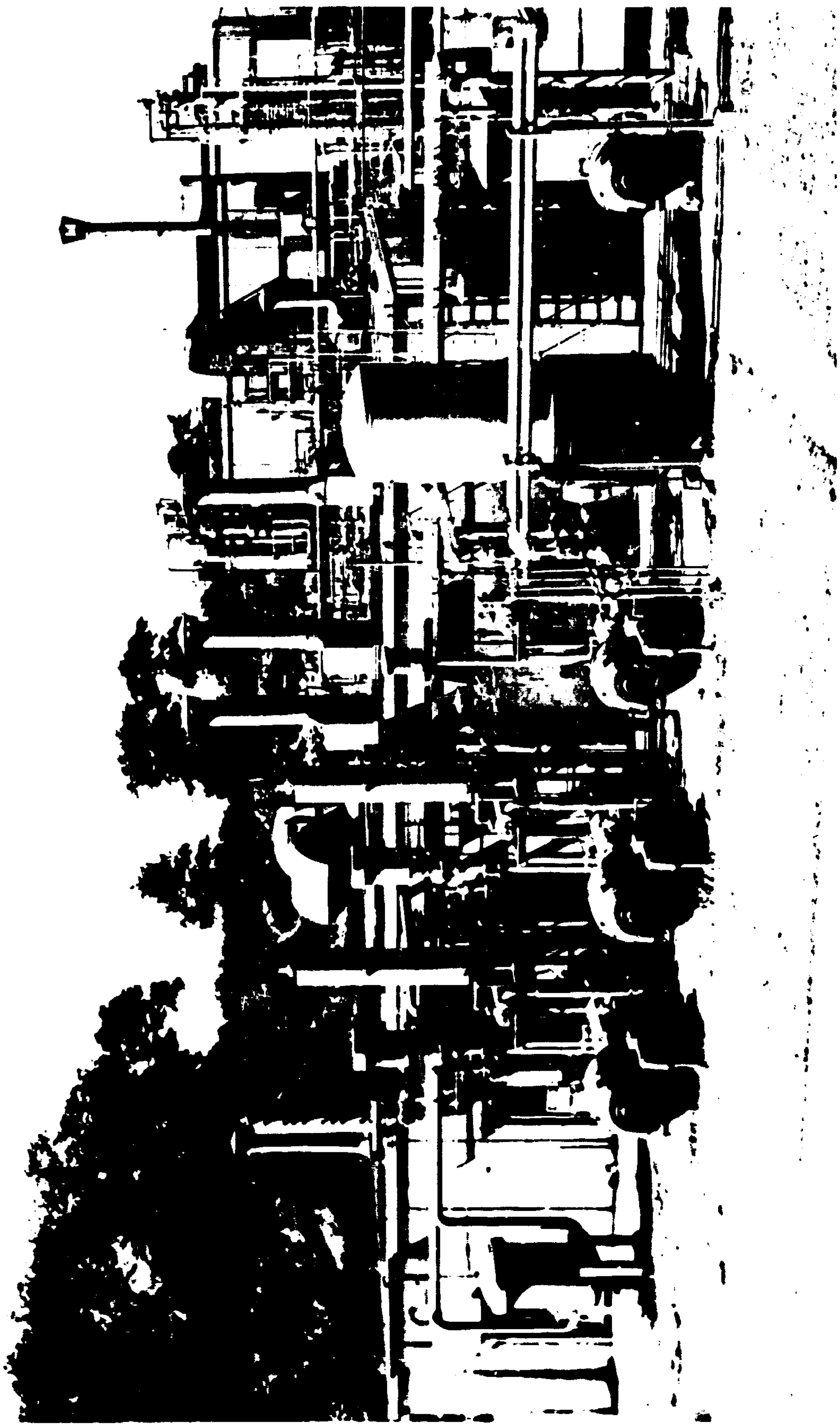


FIGURE 55
PHILLIPS RESEARCH FACILITY FOR JP FUELS

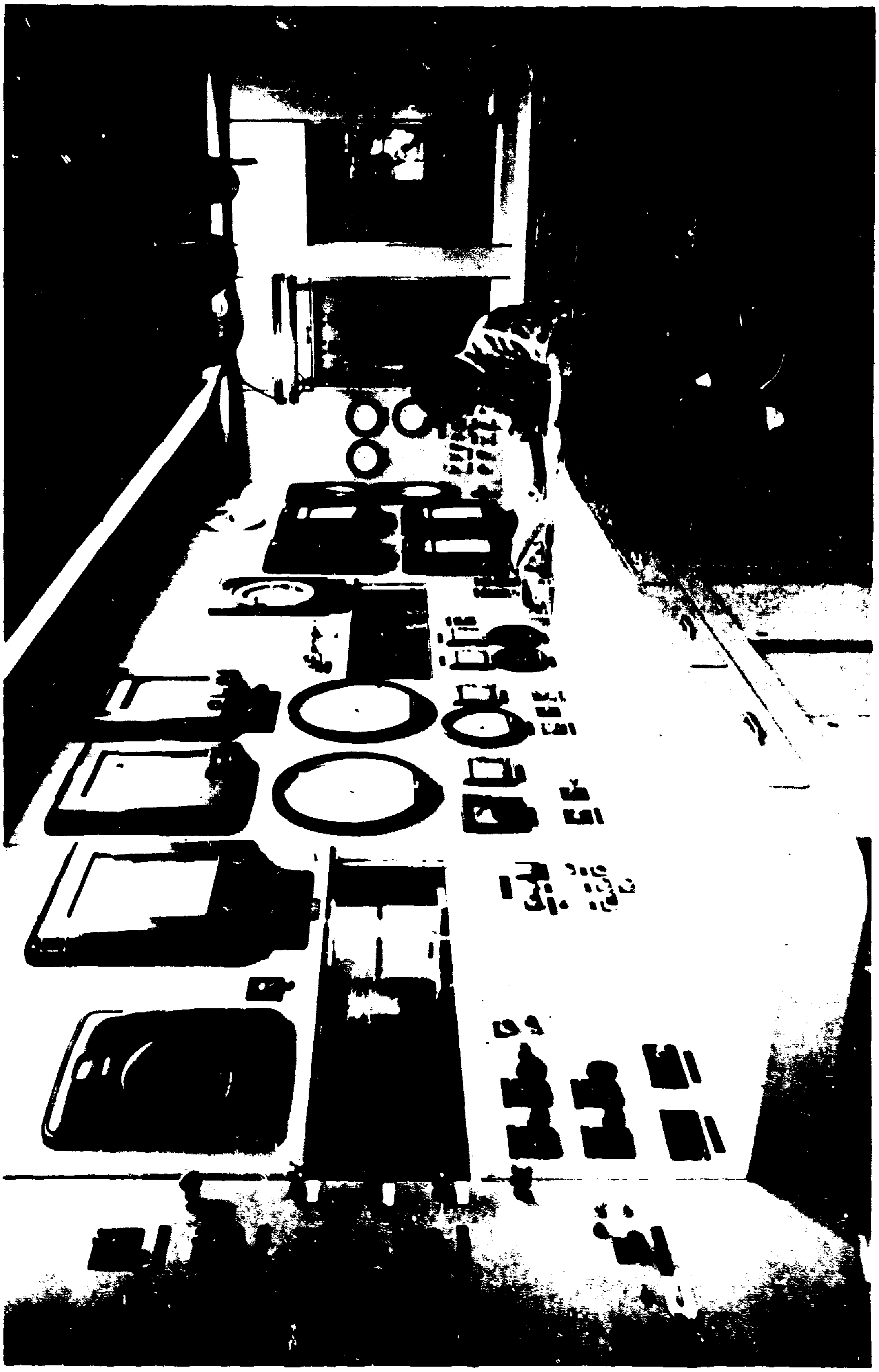


FIGURE 56
CONTROL ROOM FOR HIGH-PRESSURE COMBUSTOR

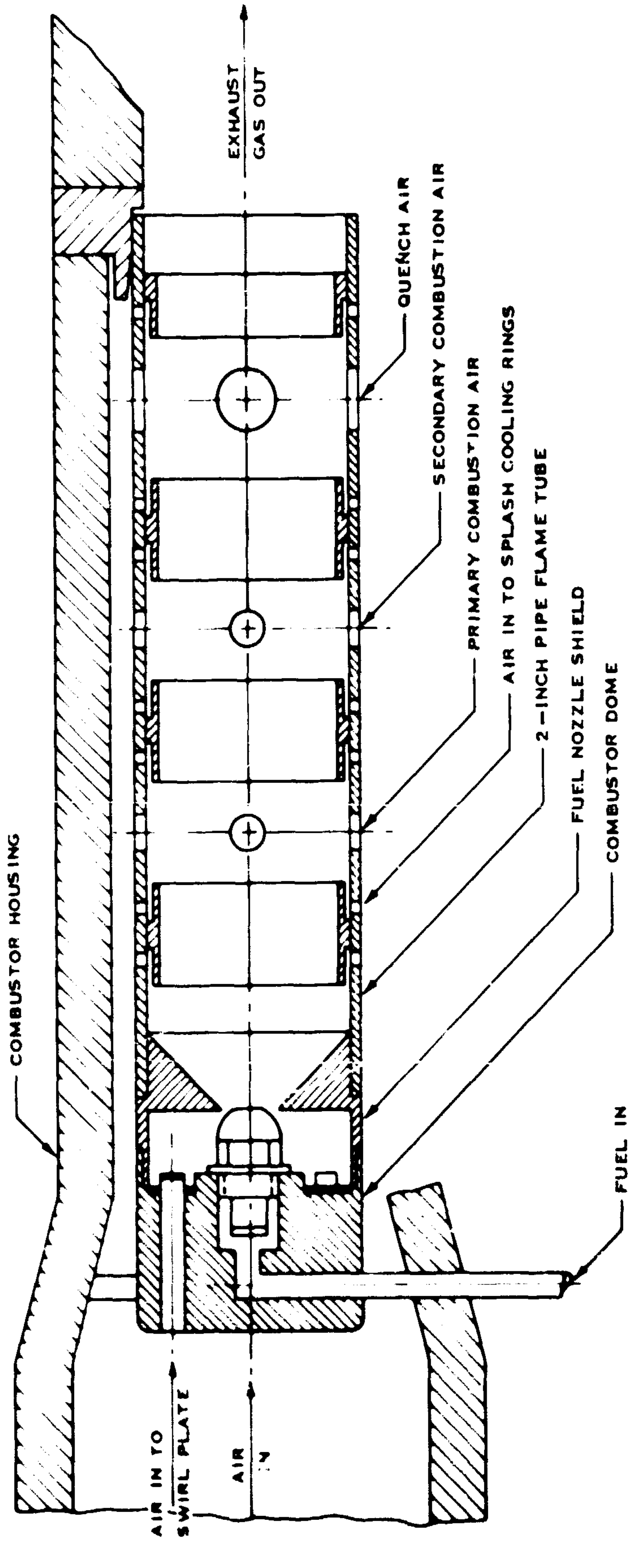


FIGURE 57
PHILLIPS 2-INCH COMBUSTOR

TABLE 44

DESIGN DETAILS OF PHILLIPS 2-INCH COMBUSTOR

Combustor Configuration Number	27
Fuel Nozzle	
Type	Simplex (Monarch)
Spray Pattern	Semi-Solid Cone (PLP)
Spray Angle, degrees	50
Capacity, gph @ 100 psi	13.8
Combustor Dome	
Air Inlet Type	Tangential Swirl
Shield Hole Diameter, in.	0.500
Wall Hole Diameter, in.	0.125
Number of Wall Holes	6
Total Hole Area, sq. in.	0.270
% Total Combustor Hole Area	7.7
Splash Cooling Air	
Hole Diameter, in.	0.125
Holes/Station	16
Number of Stations	7
Total Number of Holes	112
Total Hole Area, sq. in.	1.374
% Total Combustor Hole Area	39.1
Primary Combustion Air	
Hole Diameter, in.	0.250
Total Number of Holes	4
Total Hole Area, sq. in.	0.196
% Total Combustor Hole Area	5.6
Secondary Combustion Air	
Hole Diameter, in.	0.375
Total Number of Holes	4
Total Hole Area, sq. in.	0.442
% Total Combustor Hole Area	12.6
Quench Air	
Hole Diameter, in.	0.625
Total Number of Holes	4
Total Hole Area, sq. in.	1.227
% Total Combustor Hole Area	35.0
Total Combustor Hole Area, sq. in.	3.509
% Cross Sectional Area	131.9

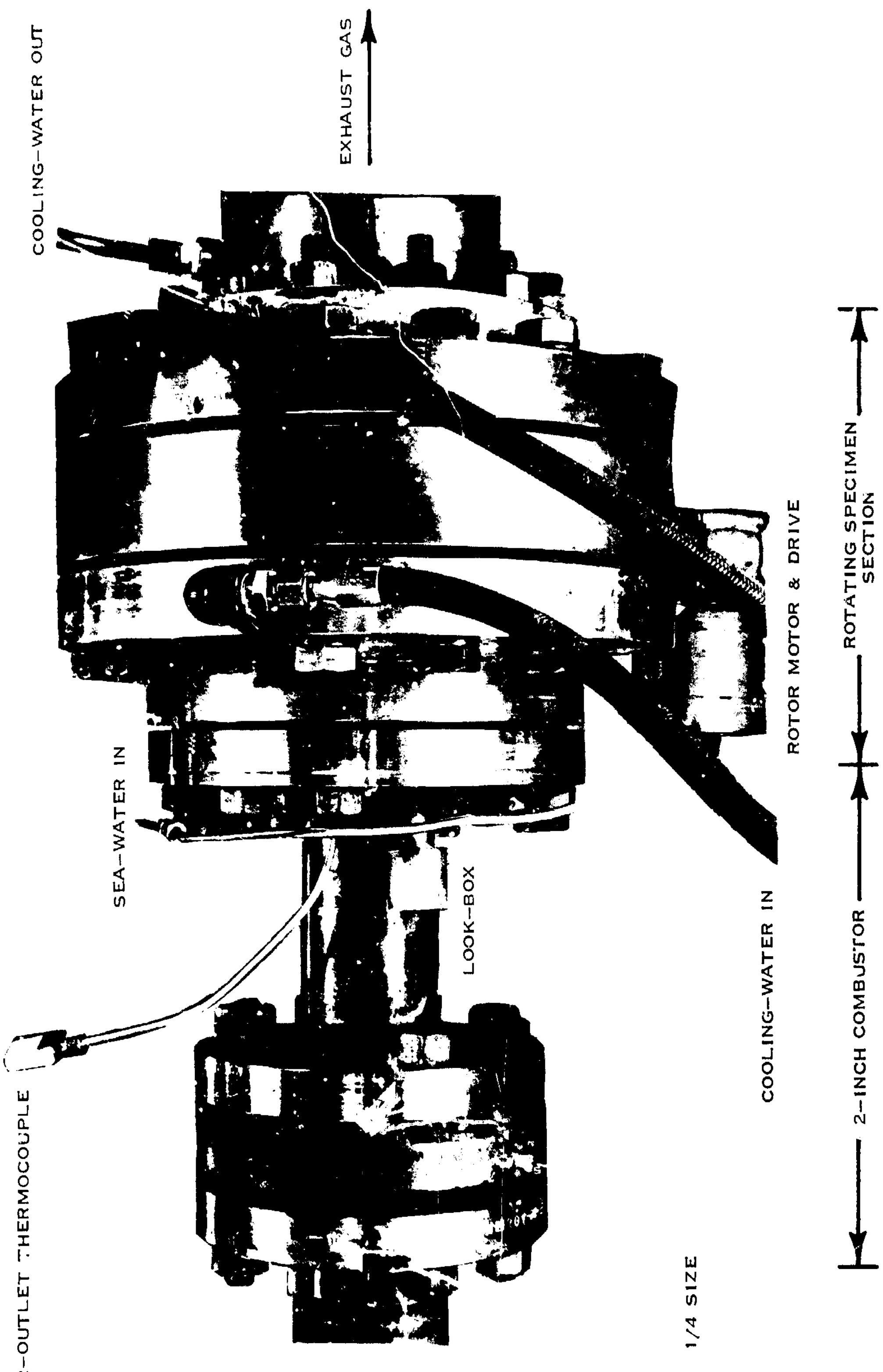


FIGURE 58
PHILLIPS TURBINE SIMULATOR FOR HOT-CORROSION STUDIES

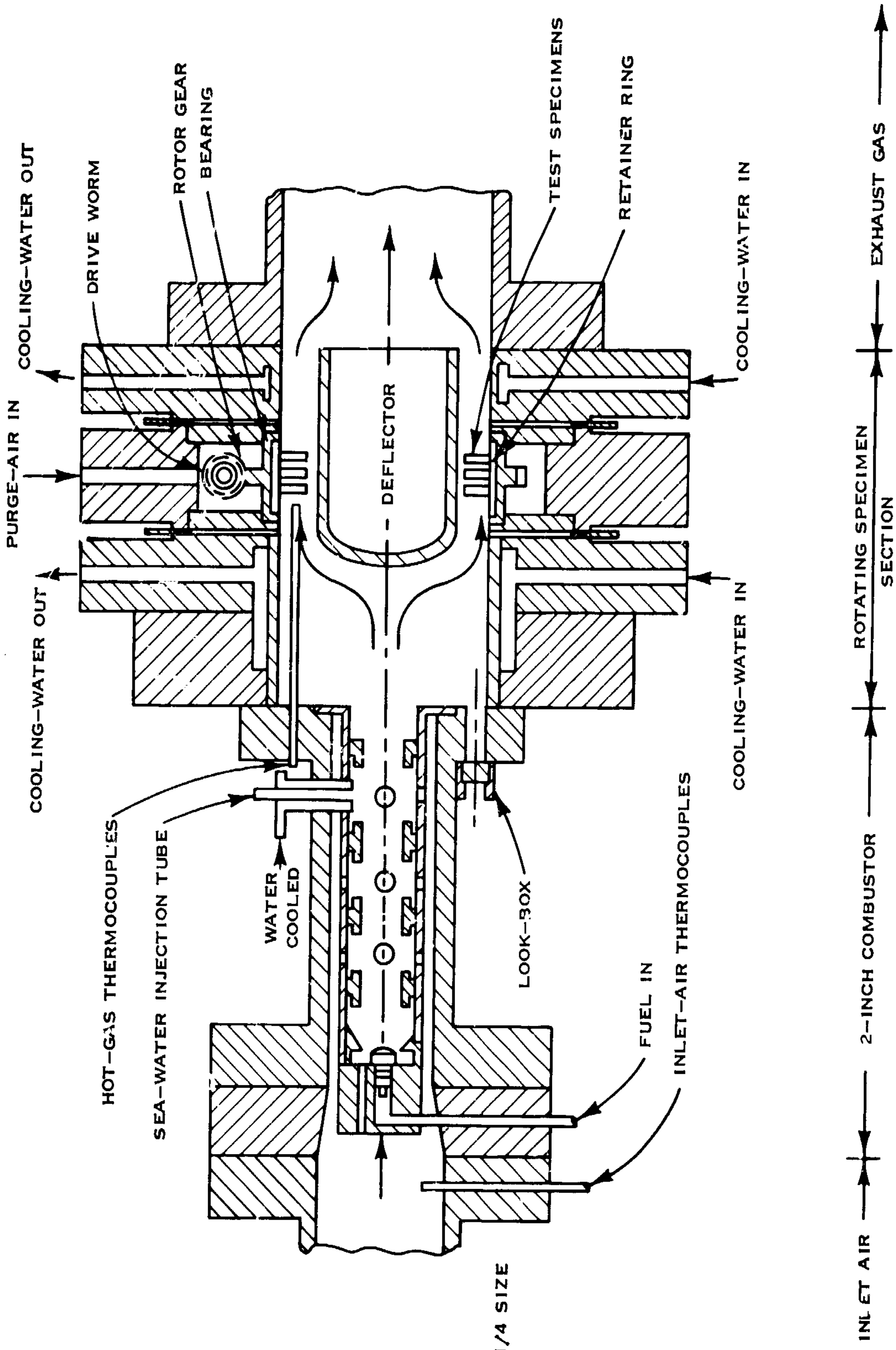


FIGURE 5

SCHEMATIC OF PHILLIPS TURBINE SIMULATOR FOR HOT-CORROSION STUDIES

The test section is water jacketed to provide the desired durability of operation with high-temperature gases.

The investment cast test specimens are round pins of the form shown in Figure 60. The design of the retainer for mounting 48 specimens in the hot gas stream from the 2-inch combustor is shown in Figure 61. The general location of the test specimens in the exhaust gas from the 2-inch combustor is shown in Figure 59. A deflector is centered in the gas stream by four equally spaced, thin plates downstream of the specimens to provide an annulus for hot gas flow on the specimens. A view of the specimen retainer, with specimens, mounted in the test rig is shown in Figure 62.

A worm-gear drive is provided to slowly rotate the specimens around the annulus and provide exposure of each test specimen to an average gas temperature. The specimens are mounted in the retainer in three rows of 16 specimens each, with each row rotated 7 1/2 degrees from the prior row and thus no specimen is in the shadow of another specimen.

Purge air is introduced into the cavity containing the worm gear drive (Figure 59) at a pressure slightly higher than combustor pressure to prevent exposure of the gear drive and bearings to the corrosive atmosphere from the combustor.

UNLESS OTHERWISE NOTED, TOLERANCE LIMIT ON DIMENSION IS ± 0.002 INCHES

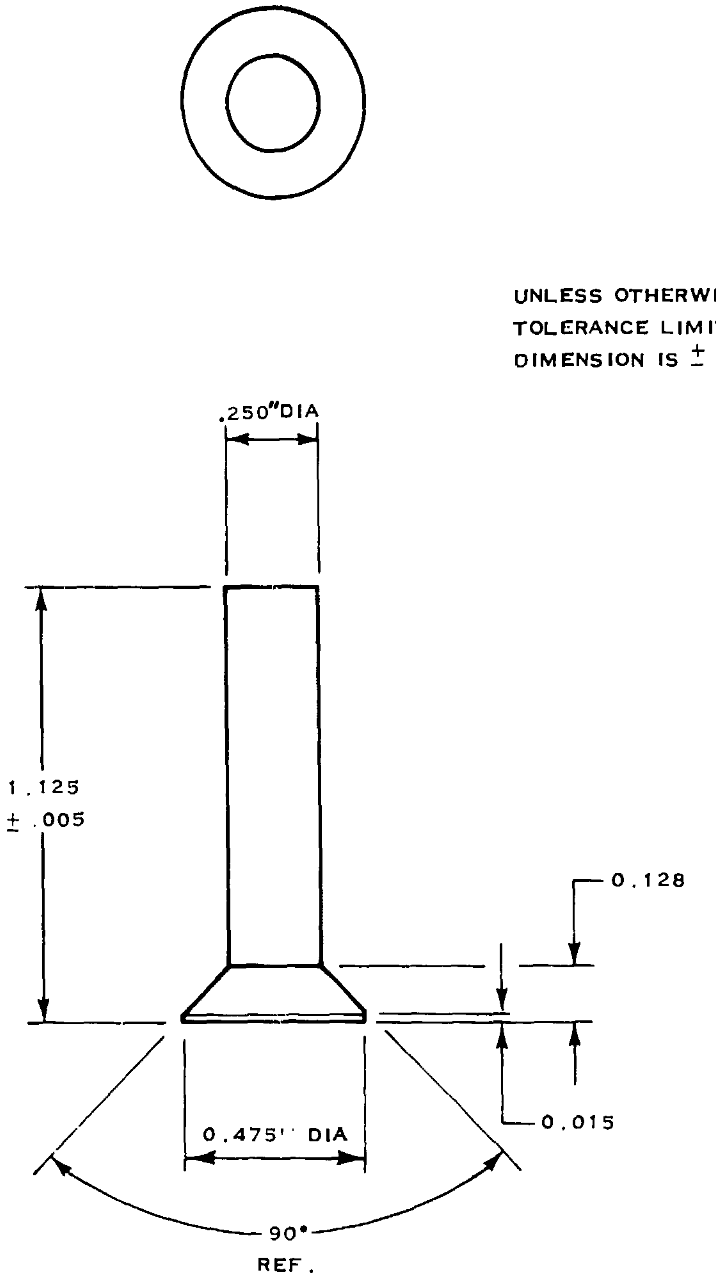


FIGURE 60
TEST SPECIMEN

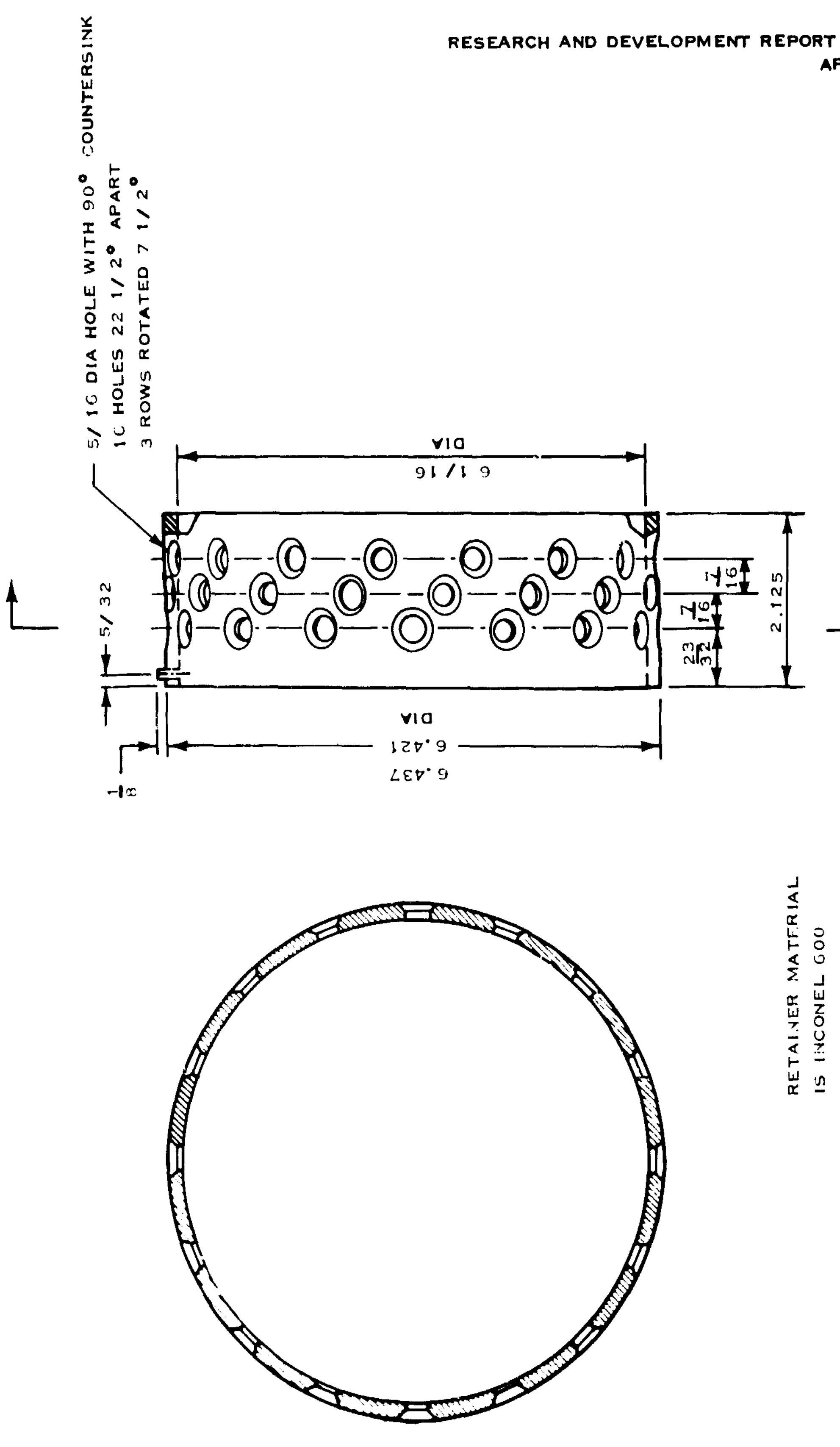


FIGURE 61
TEST SPECIMEN RETAINER

FULL SIZE

FIGURE 62
ROTATING-SPECIMEN SECTION OF PHILLIPS TURBINE SIMULATOR

9. APPENDIX 2

(Materials)

9.1. Test Specimens

In consultation with U.S. Navy personnel, engine builders and alloy suppliers, a group of eight nickel-base and four cobalt-base superalloys were selected for inclusion in the program. Test specimens of these twelve superalloys were prepared as investment castings by the Misco Division of Howmet Corporation. Their chemical analysis, as certified by the supplier, is shown in Table 45. These data serve to illustrate the broad range in composition represented by this selection of superalloys.

Similarly, two aluminide coatings were selected for inclusion in the program: i.e., an aluminum-rich and an aluminum-chromium-rich diffusion coating. Since such coatings were available from the Reactive Metal Products Division of Howmet Corporation, and since Misco MDC-1 and Misco MDC-9 coatings have demonstrated satisfactory performance characteristics in previous investigations (12, 13, 14, 15), they were selected to minimize procurement problems. These coatings are characterized by the following descriptions.

> MDC-1 is an aluminum coating, which was applied by a pack-diffusion process to obtain a total thickness of approximately 2-3 mils. It is divided about equally between an outer layer, which contains non-metallic dispersions, and a diffused zone.
>
> MDC-9 is a composite coating, rich in aluminum and chromium, which was applied by a pack-diffusion process to obtain a total thickness of approximately 2-3 mils. The inner diffused zone is less than half the total coating thickness.

The MDC-9 coating was applied to all the nickel-base specimens during a batch operation, and to all the cobalt-base specimens during another batch operation. Similarly, the MDC-1 coating was applied to all the nickel-base specimens during a batch operation, with the exception of Mar M-200 which was not available at the time because of casting difficulties and which was coated separately. This is shown in Table 46, along with the metallographic measurement of coating thickness--which varies with composition of the superalloys.

The dimensions of the test specimens are shown in Figure 60. The investment castings were finished by grinding the base and inspected to provide specimens having a smooth uniform finish and uniform dimensions with a tolerance of ±0.005 inches. The specimens were inspected by fluorescent penetrant (Zyglo) and X-ray to insure freedom from cracks, porosity and inclusions. From specification dimensions, the surface area was calculated to be 7.76 square centimeters. The average weight of bare specimens from a random sample of ten of each of the twelve superalloys was 8850 milligrams.

9.2. Test Fuels

The base fuel selected for use in this investigation was a segregated sample of Phillips Base Oil No. 1. The physical and chemical properties

TABLE 45

COMPOSITION OF TEST SPECIMENS

Chemical Analysis, wt % (a)

Alloying Elements	Nickel-Base Alloys								Cobalt-Base Alloys			
	U-710	IN-738	U-700	I-713C	IN-100	MM-200	MM-246	B-1900	X-40	MM-509	MM-302	WI-52
Nickel	54.6(b)	60.6(b)	58.0(b)	72.1(b)	60.4(b)	60.2(b)	59.6(b)	63.5(b)	10.40	9.84	1.48	0.70
Cobalt	14.90	8.53	15.[illegible]	0.05	15.40	10.0	10.10	9.98	55.4(b)	57.0(b)	54.2(b)	62.5(b)
Chromium	18.20	16.40	[illegible]	13.50	9.90	8.99	8.69	8.47	26.10	21.20	21.30	20.70
Aluminum	2.40	3.50		6.14	5.64	5.01	5.47	5.85	....	....	....	....
Titanium	5.00	3.49	3.4[illegible]	0.77	4.12	1.98	1.52	1.00	....	0.20	....	....
Molybdenum	2.90	1.74	4.20	4.61	2.95	....	2.69	6.04	....	....	....	....
Tungsten	1.45	2.56	....	....	....	12.20	10.00	<0.1	7.20	6.90	10.80	11.00
Tantalum	....	1.93	....	....	....	....	1.39	4.42	....	3.37	9.60	....
Columbium	....	0.70	....	....	....	1.02	....	<0.1	....	....	....	....
Cb + Ta	....	....	....	2.26	....	....	....	....	....	....	....	2.23
Zirconium	....	0.09	<0.04	0.10	0.07	0.05	0.05	0.10	0.10	0.50	0.20	....
Vanadium	....	....	....	....	1.02	....	....	....	....	....	....	....
Manganese	<0.1	0.02	<0.1	<0.05	<0.1	<0.1	<0.1	<0.05	<0.1	<0.1	<0.1	0.19
Iron	0.10	<0.1	0.10	<0.1	0.10	<0.1	0.08	0.20	<0.1	0.14	1.10	1.90
Silicon	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.15	<0.1	0.32	0.28
Carbon	0.07	0.166	0.07	0.124	0.19	0.14	0.144	0.096	0.455	0.63	0.87	0.476
Boron	<0.05	0.010	0.014	0.005	0.015	0.019	0.011	0.011	0.006	....	0.009	....
Phosphorus	....	....	<0.1	....	....	....	....	....	....	....	....	0.009
Sulfur	0.003	0.001	0.003	0.003	0.003	0.003	0.004	0.003	0.002	0.009	....	0.012
Copper	<0.1	....	<0.1	<0.1	....	<0.1	<0.1	....	....	....	....	....
Heat No.(c)	66884	AC003	MJ319	RW675	UA023	RL095	KB001	MG275	CB015	BC003	RM571	MF293

(a) Certified by Misco Division, Howmet Corporation.
(b) Calculated as balance.
(c) Misco Division, Howmet Corporation

TABLE 46

COATINGS ON TEST SPECIMENS

Superalloy		Misco MDC-1		Misco MDC-9	
Designation	(a) Heat Number	(b) Lot Number	(c) Thickness, Mils	(b) Lot Number	(c) Thickness, Mils
Nickel-Base					
Udimet 710	66884	5812-1	2.0	5964-1	3.5
IN-738	AC003	"	2.8	"	1.9
Udimet 700	MJ319	"	2.4	"	3.5
Inconel 713C	RW675	"	3.1	"	3.2
IN-100	UA023	"	2.6	"	3.2
Mar M-246	KB001	"	3.0	"	2.7
B-1900	MG275	"	2.8	"	2.0
Mar M-200	RL095	5911-1	2.3	"	3.2
Cobalt-Base					
X-40	CB015	....	...	5716-1	2.2
Mar M-509	BC003	....	...	"	2.3
Mar M-302	RM571	....	...	"	2.8
WI-52	MF293	....	...	"	2.7

(a) Misco Division, Howmet Corporation.

(b) Reactive Metal Products Division, Howmet Corporation.
(Specimens having the same Lot Number were coated at the same time, with the same pack, in the same retort.)

(c) Certified by Reactive Metal Products Division, Howmet Corporation.

of interest to the investigation are presented in Table 47. The average values of pertinent properties from the Bureau of Mines Product Survey (17) over a period of the past ten years are also shown for grade JP-5 aviation-turbine fuel. The physical and chemical properties of the base fuel closely approximate the average of JP-5, with the exception of its very low sulfur content and low aromatic content. The base fuel was analyzed for metal content to be certain that its iron, vanadium, nickel, and copper contents were negligible; if present, they would concentrate as ash and might alter the scale composition on the test specimens exposed to the exhaust gases.

The base fuel contains 0.0004 weight percent sulfur and was selected as an esentially sulfur free fuel. Test fuels with 0.004 and 0.04 weight per cent sulfur have been blended from the same batch of fuel, for use in an experimental investigation (11) of the effect of sulfur in fuel on hot corrosion of turbine-blade materials, using ditertiary butyl disulfide. The data obtained in Reference 11 using 0.04 weight per cent sulfur in test fuel will be used as the base line for the current investigation. Fuel from the blend containing 0.04 weight per cent sulfur was treated with 0.1 volume per cent of "Ethyl" Combustion Improver-2 (methylcyclopentadienyl-manganese-tricarbonyl) to provide the fuel for the current investigation. Typical properties of the fuel additive are shown in Table 48.

9.3. Sea Water

A synthetic sea water was used in this study. Its formulation conforms to ASTM Method D 665 (18). The components and their concentrations are shown in Table 49. The abundance of various elements in the synthetic formula compares very favorably with the average sea-water composition (19).

As discussed in Reference 12, establishing a realistic level for the concentration of sea salt in air ingested by a gas-turbine engine operating in a marine environment is difficult from available literature. However, it was concluded that an ingestion rate of 1.0 ppm sea salt was a realistic level. A concentration of 1.0 ppm sea salt in air was used in this investigation.

TABLE 47

PHYSICAL AND CHEMICAL PROPERTIES OF TEST FUEL

	Test Fuel Base (a)	Average JP-5 (b)
Distillation Temperature, F		
Initial Boiling Point	366	-
5 Volume per cent evaporated	373	-
10 Volume per cent evaporated	374	383
20 Volume per cent evaporated	376	-
30 Volume per cent evaporated	380	-
40 Volume per cent evaporated	386	-
50 Volume per cent evaporated	392	412
60 Volume per cent evaporated	400	-
70 Volume per cent evaporated	412	-
80 Volume per cent evaporated	433	-
90 Volume per cent evaporated	467	455
95 Volume per cent evaporated	500	-
End Point	553	-
Gravity, degrees API	52.4	42.0
Gum, milligrams per 100 mls	1.1	1.0
Smoke Point, millimeters	38.1	22.6
Hydrogen Content, weight per cent	15.2	-
Composition, parts per million		
Sulfur	4(c)	950
Metals		
Iron	<0.1	-
Vanadium	<0.2	-
Nickel	<0.2	-
Copper(d)	<0.03	-
Hydrocarbon Types, volume per cent		
Paraffins	96.9	-
Olefins	0.6	1.5
Aromatics	2.5	15.8

Notes:

(a) Values for segregated sample of Phillips Base Oil No. 1.

(b) U. S. Bureau of Mines Petroleum Product Survey, 1959 - 1968 (17)

(c) Higher sulfur content test fuels obtained by blending to desired sulfur levels using ditertiary butyl disulfide.

(d) Spectro-photometric analysis.

TABLE 48

TYPICAL PROPERTIES OF "ETHYL" COMBUSTION IMPROVER-2
(Methylcyclopentadienyl-manganese-tricarbonyl)

Form	Liquid
Color	Straw Colored
Odor	Faint, pleasant, herbaceous
Empirical Formula	$C_9H_7O_3Mn$
Molecular Weight	218.1
Manganese, Wt. % (Minimum)	24.7
Density at 68°F	
g/ml	1.3884
lb/gal	11.589
Viscosity at 68°F, cp	5.11
Flash Point (open cup), °F	233
Freezing Point, °F	34.6
Solubility in hydrocarbon	Soluble in all proportions at 68°F in distillate stocks
Solubility in Water at 77°F, ppm	70

TABLE 49

COMPOSITION OF SYNTHETIC SEA WATER (a)

Salt (b)	Formula	Grams per liter (c)
Sodium Chloride	$NaCl$	24.54
Magnesium Chloride	$MgCl_2 \cdot 6H_2O$	11.10
Sodium Sulfate	Na_2SO_4	4.09
Calcium Chloride	$CaCl_2$	1.16
Potassium Chloride	KCl	0.69
Sodium Bicarbonate	$NaHCO_3$	0.20
Potassium Bromide	KBr	0.10
Boric Acid	H_3BO_3	0.03
Strontium Chloride	$SrCl_2 \cdot 6H_2O$	0.04
Sodium Fluoride	NaF	0.003
	TOTAL	41.953

(a) ASTM D665 (18)

(b) Use cp chemicals.

(c) Use distilled water.

10. APPENDIX 3

(Procedures)

10.1. Pre-Test Cleaning

New specimens were cleaned by vapor degreasing with trichloroethylene, using the apparatus shown diagrammatically in Figure 63. Cleaned specimens were handled with degreased stainless-steel tongs. The initial weight of each specimen was determined following degreasing.

10.2. Post-Test Cleaning

After exposure for the scheduled periods of time the specimens were removed from the turbine simulator and reweighed. Surface scale on specimens was removed for subsequent compositional analysis by lightly scraping with a blunt stainless-steel spatula. Following removal of a sample of the surface scale the specimens were cleaned to allow for a measurement of the weight of metal that was lost from the specimen by immersing the specimens in molten sodium hydroxide at 750 to 790 F with 1/3 amp/sq cm passing through the specimens for a period of 10 minutes. The specimens were then scrubbed under a flowing stream of water with a stainless-steel wire brush, rinsed in acetone, dried, and reweighed. The apparatus for electro-cleaning specimens is shown diagrammatically in Figure 64.

10.3. Metallographic Examination

One specimen of each of the 12 different superalloys and 20 different superalloy-coating systems, in the as-received condition, was sectioned, mounted, and polished for metallographic examination. Photomicrographs were taken at 500X magnification, using a Bausch & Lomb Research Metallograph, to show the typical condition of the surface and matrix of these unexposed specimens. Also, measurements of coating thickness were made to confirm the vendor's certification.

Following electro-cleaning, but otherwise in the as-received condition, one specimen of each test material was subjected to a similar microexamination to show any unusual effect which such treatment might have on the bare surface of the superalloys or on their coatings.

Following exposure in the turbine simulator and subsequent electrocleaning, one specimen of each test material was subjected to a similar microexamination to show the mode and intensity of hot-corrosion attack. When available, specimens were selected that had been given visual ratings of 6, which indicates a metal weight-loss of near 100 mg/cm^2 on the bare superalloys and near 50 mg/cm^2 on the coated superalloys. These specimens were not sectioned specifically at the point of maximum-visible attack for measurement of the depth of corrosive attack; rather, evidence was sought to establish the mode by which the aggressive thermal environment deteriorated the protective coatings and penetrated the base alloy. For this purpose, photographs were taken of the specimens before sectioning, photomacrographs were taken of their cross-sections at 9X magnification, and photomicrographs were taken at 100X, 500X, and 2000X magnification to show the morphology of hot-corrosion attack

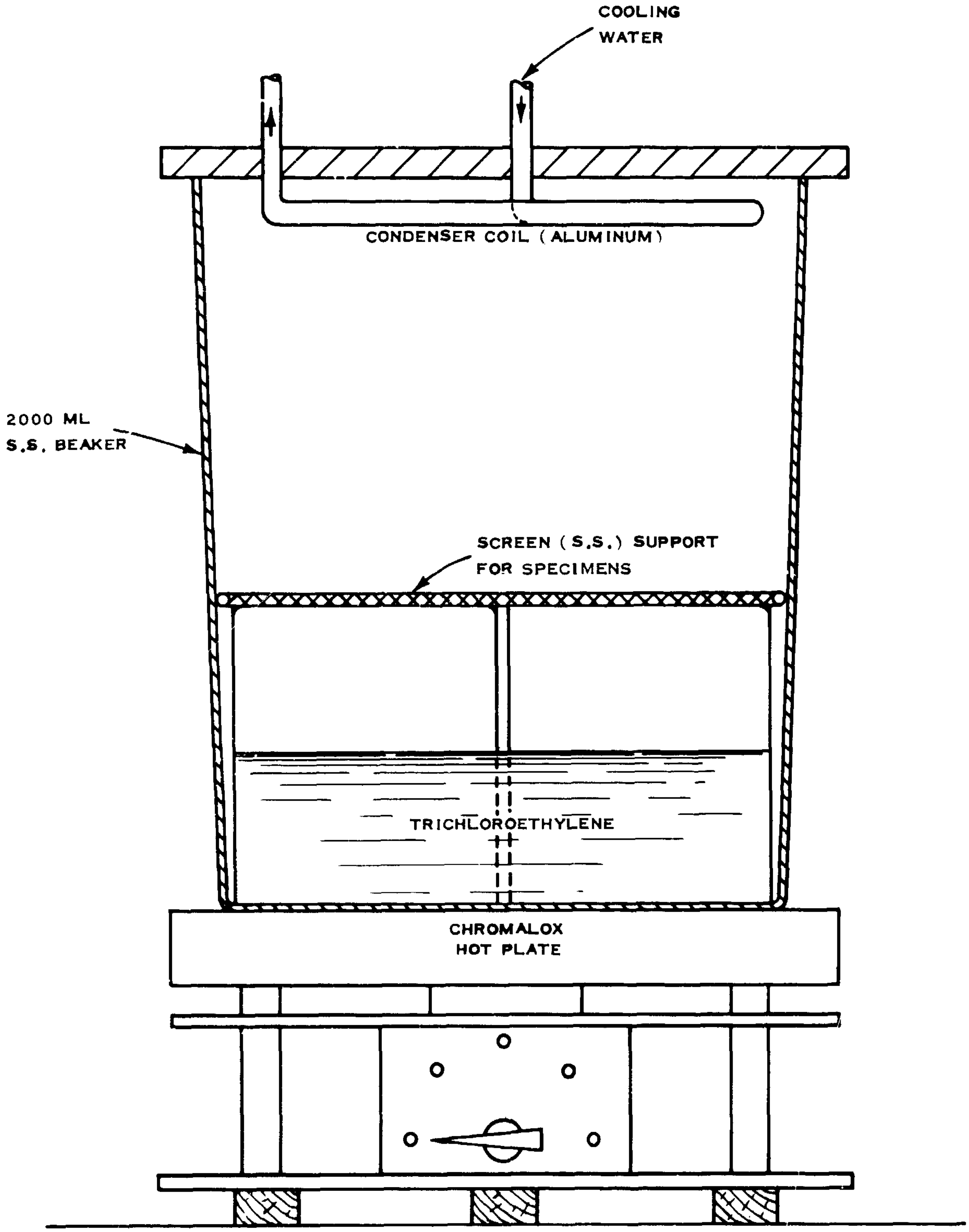


FIGURE 63
VAPOR-DEGREASING APPARATUS FOR PRE-TEST CLEANING OF SPECIMENS

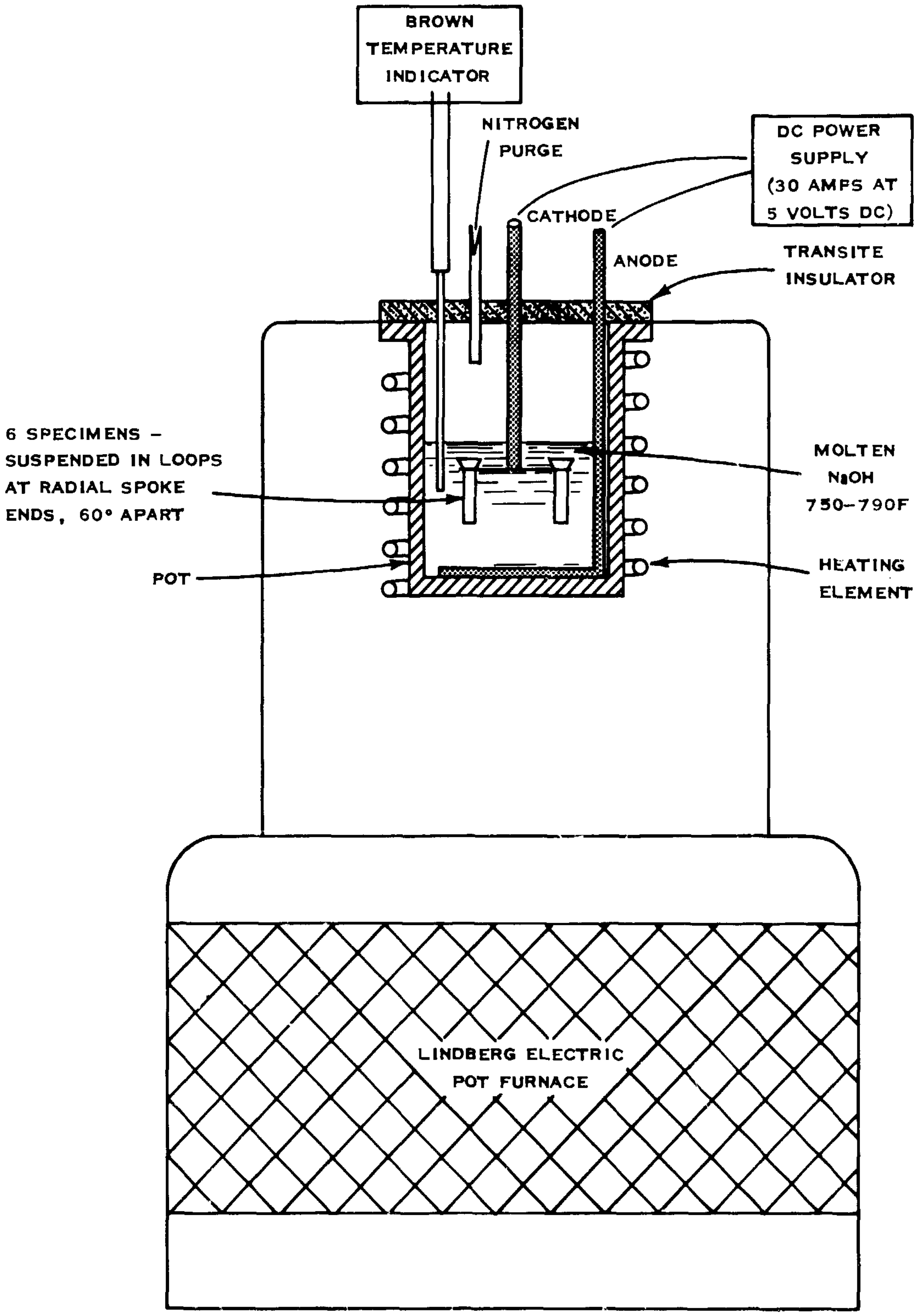


FIGURE 64
ELECTRO-DESCALING APPARATUS
FOR POST-TEST CLEANING OF SPECIMENS

on these 12 different superalloys and 20 different superalloy-coating systems exposed in Phillips Turbine Simulator at the test conditions employed during this investigation.

The coupons for metallographic examination were centered inside pieces of 1/2-inch diameter steel tubing and mounted in 1-inch diameter red Bakelite molds. This arrangement aided in obtaining a flat surface on the coupon during polishing. The following eight step technique was used to polish the coupons.

(a) Dry ground on 180 grit Carbimet wheel (8-inch diameter disc turned at 570 RPM).

(b) Dry ground on 120 grit Carbimet wheel (8-inch diameter disc turned at 570 RPM).

(c) Hand lapped on 240 grit silicon carbide paper (wet).

(d) Hand lapped on 320 grit silicon carbide paper (wet).

(e) Hand lapped on 400 grit silicon carbide paper (wet).

(f) Hand lapped on 600 grit silicon carbide paper (wet).

(g) Polished on nylon lap using 6-micron diamond paste with polishing oil.

(h) Polished on AB micro cloth using Linde B Polishing compound.

Considerable difficulty from spalling of the Misco MDC-9 coating was experienced during preparation of the unexposed specimens for metallographic examination. Edge retention was greatly improved by nickel plating these specimens to protect the brittle coating during sectioning and polishing.

The polished coupons were etched to facilitate identification of the outer layer and diffusion zone of the coatings, and the extent of alloy depletion at the corrosion interface. This was done electrolytically with 10% oxalic acid on the nickel-base alloys, and with 10% sodium nitrate on the cobalt-base alloys; however, the latter was found to be too severe for some of the Misco MDC-9 coating systems and Murkami's reagent was used to etch these cobalt-base alloys.

This examination of representative specimens indicated that weight-loss may not reflect the extent of total metal damage because of localized attack on low-chromium superalloys and subsurface corrosion on high-chromium superalloys. Therefore, all the specimens from the test with Ethyl CI-2 added to the fuel and all the corresponding specimens from the base-line test were photographed, sectioned, mounted and polished, using procedures already described, for an additional evaluation based on metallographic measurement of penetration by the corrosive attack. For this purpose, we used the procedure promulgated by the ASTM Turbine Panel for the round-robin test program of the Hot Corrosion Task Force (20), which is as follows:

Metallographic Measurements. Two cross-sectional areas of each specimen are mounted for examination. One represents a zone of maximum visual attack and the other represents a zone of average visual attack. For a specimen corroded over half or less of its length, the sections are taken in a corroded zone and noncorroded zone. Each of the cross-sectioned areas are measured for hot-corrosion effects across two diameters approximately 90° apart; thus, each specimen is measured in four places. Two types of hot-corrosion effects are determined; these are gross (massive) attack and maximum attack, illustrated in Figure 65. All values are reported as loss in diameter (mils).

Surface Loss (Gross Attack) is a measurement of all material loss, plus any massive oxidation and sulfidation; it does not factor in other types of subsurface attack such as intergranular attack. For each specimen, four measurements are reported to show the consistency of attack. The measurements are averaged together, and this new value reported and plotted as the gross attack.

Maximum Attack is a measurement which includes gross attack plus the depth of penetration of all sulfides and oxides, which may be scattered or in local concentrations; e.g., grain boundaries. The depth of subsurface oxides and sulfides may vary from one side of the specimen to the other side; thus, measurements in terms of loss in diameter are qualified as attack on both sides (B), mostly on one side (M), and on one side (O). A measurement for each cross-sectioned area is reported to indicate the consistency of attack, but only the greatest value is considered the maximum attack for the alloy.

10.4. Specimen Rating

After each five hours of exposure a binocular microscope at 10X magnification was used to inspect each of the 48 specimens in the specimen retainer to estimate the extent of corrosive attack and the time for failure for the coated superalloys. To aid in the inspection of the specimens each specimen was assigned a rating based on the scale shown in Table 50.

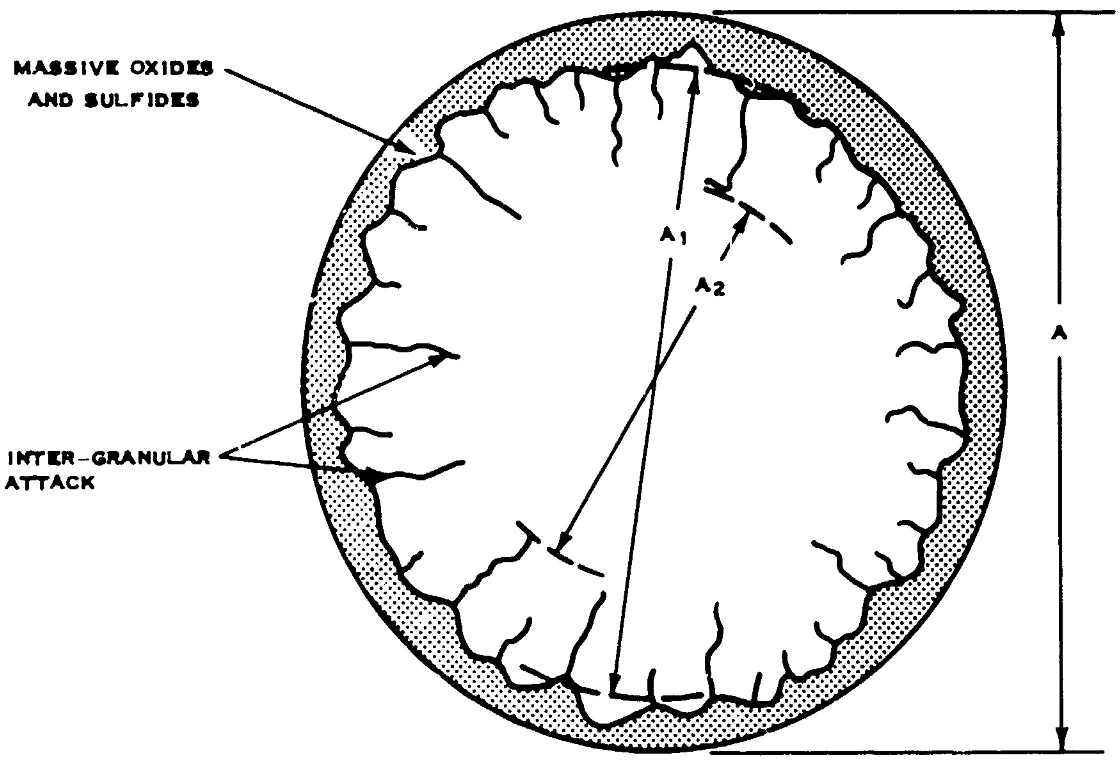
10.5. Turbine Simulator Operation

The Phillips Test Facility and Turbine Simulator are described in Section 8 which is Appendix 1 of this report.

The Phillips Turbine Simulator was operated under the cyclic temperature conditions of Table 51 for periods of five hours. At the completion of each five hour period, the test rig was disassembled and the specimen retainer removed for visual inspection and rating of the specimens.

Purge air was introduced into the cavity surrounding the test-specimen retainer throughout the cycle, at the location indicated in Figure 59, at a flow rate of 324 lb/hr to minimize contact of combustion products with the specimen-retainer bearings and worm-gear drive.

Sea-water solution was injected at a flow rate of 1.75 pounds per hour per jet or 3.5 pounds per hour total. Flow was maintained through the



A = ORIGINAL DIAMETER, MEASURED WITH A MICROMETER
A_1 = DIAMETER OF STRUCTURALLY USEFUL METAL, MEASURED AT 100X
A_2 = DIAMETER OF METAL UNAFFECTED BY OXIDES AND SULFIDES, MEASURED AT 100X
SURFACE LOSS: $A-A_1$ LOSS IN DIAMETER DUE TO MASSIVE OXIDES AND SULFIDES
MAXIMUM ATTACK: $A-A_2$ LOSS IN DIAMETER DUE TO ALL FORMS OF OXIDATION AND SULFIDATION

FIGURE 65
METHOD OF MEASURING HOT-CORROSION ATTACK

TABLE 50

RATING SCALE FOR HOT CORROSION TEST SPECIMENS

Rating	Extent of Attack
10	No attack
9	Surface rough on coating or very light attack on bare specimen
8	Blister or failure of coating on corners (May have indications of color)
7	Progressive attack on coating or light attack on bare specimen
5	Medium attack
3	Heavy attack
1.	Very heavy attack ($\cong$3/32 inch diameter of specimen)

TABLE 51

OPERATING CONDITIONS FOR PHILLIPS TURBINE SIMULATOR

Test Variables	Test Condition					
Temperature, deg F						
Exhaust Gas at						
Test Specimens	1600	1000	1800	1000	2000	1000
Combustor Inlet Air	1000	1000	1000	1000	1000	1000
Pressure, atmospheres						
Combustor Inlet Air	15	15	15	15	15	15
Mass Flow Rate, lb/hr						
Purge Air	324	324	324	324	324	324
Combustor Air	6660	6660	6660	6660	6660	6660
Fuel	73.8		97.4		121.0	
Water (a)		49		49		49
Air-Fuel Ratio	90		68		55	
Flow Velocity, ft/sec						
at Test Specimen (b)	230	163	253	163	275	163
Cycle Time, minutes	8	2	8	2	8	2

(a) Water flow through nozzle while fuel is off.

(b) Calculated value based on unblocked area in specimen retainer of 4.00 square inches.

jets during fuel-off as well as fuel-on portions of the operating cycle. Sea water (Table 49) was diluted with deionized water to give a concentration of 1.0 ppm sea salt in combustor air.

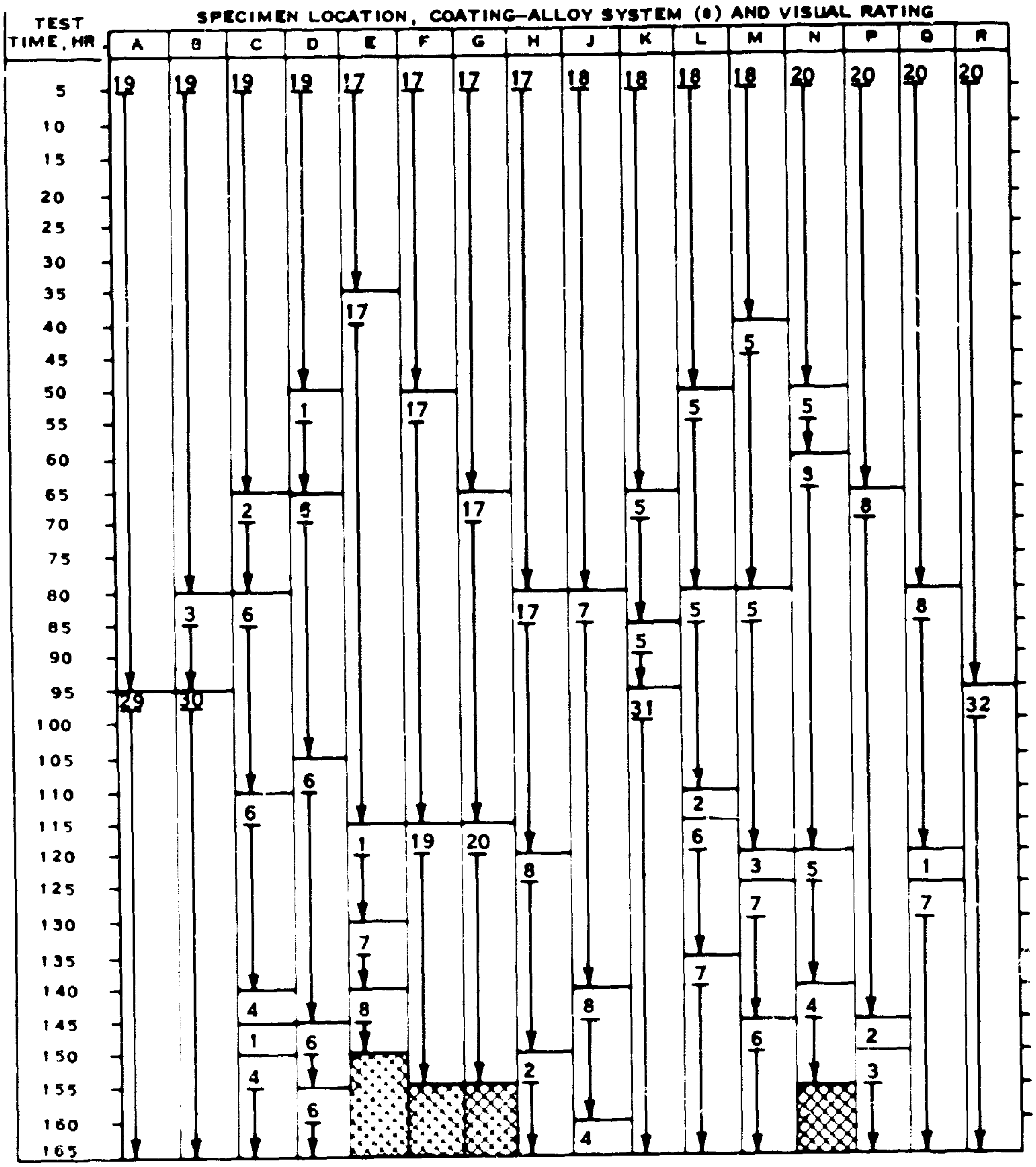
10.6. Test Plan

The test plan for this experimental investigation has been designed to place primary emphasis on obtaining information on the effect of a fuel additive on surface scale accumulations and hot corrosion of turbine-blade materials exposed at high temperatures in marine environment. In addition to providing information for this primary objective, the design also permits limited comparisons of the relative durability of the superalloys and superalloy coating systems.

The tests of this investigation consisted of runs with two fuels, one with and one without 0.1 volume per cent Ethyl Combustion Improver No. 2 (CI-2). The tests were conducted with fuels containing 0.040 weight per cent sulfur and with 1.0 ppm sea salt in combustor air to expose specimens of superalloys and superalloy-coating systems in the Phillips Turbine Simulator using a temperature cycle of 30 minutes, with a maximum temperature in the cycle of 2000 F.

It would be desirable to obtain duplicate four-point curves of weight-loss with time of exposure for each of the superalloys and superalloy-coating systems; however, this could not be accomplished in the time available and duplicates were scheduled on a limited number of test materials. In scheduling duplicates, materials were selected to represent various levels of specimen durability to aid in obtaining a representative estimate of experimental error for use in comparisons of the additive effects and superalloy durability. Duplicates were scheduled for different periods of time during the test rather than being exposed simultaneously in order to include all components of experimental error.

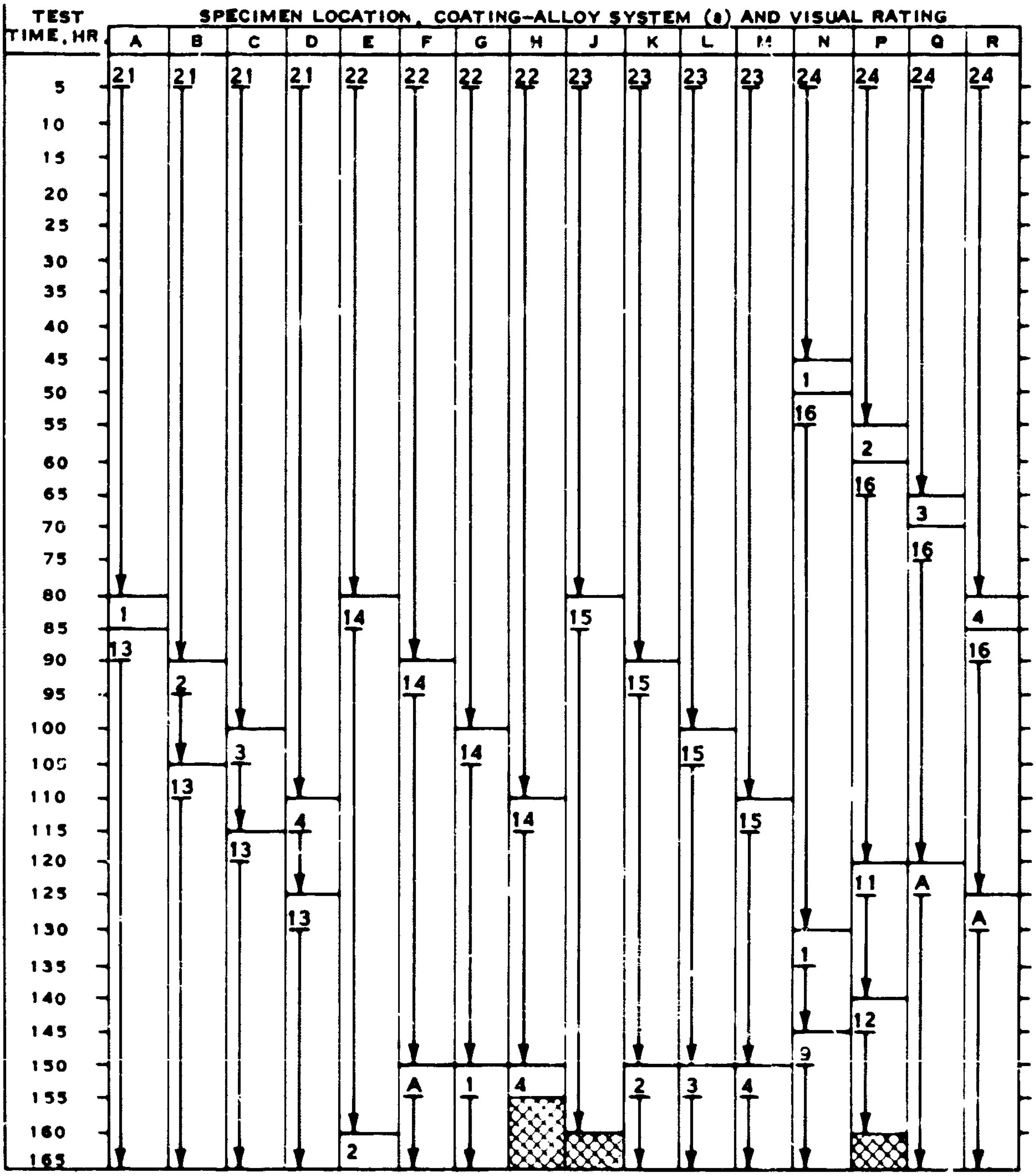
The schedule for exposure of materials was designed to minimize the effect of any possible difference in severity of the three rows of the specimen retainer by scheduling exposure of specimens of a superalloy or superalloy-coating system in a single row of the specimen retainer. In the base line test (11), specimens of the four least durable superalloys were exposed in duplicate in each of the three rows of the specimen retainer to provide information to permit an estimate of any effect of position in the specimen retainer on severity of hot-corrosion attack. The schedule of specimen exposure for the base-line test for each of the three rows of the specimen retainer is shown in Figures 66, 67, and 68 and a summary of the number of specimens of each material and hours of exposure is shown in Table 52. The schedule of specimen exposure for the test using CI-2 additive in the fuel was revised to eliminate exposure of specimens of the four least durable superalloys in two of the three rows of the specimen retainer. The schedule of exposure of specimens in each of the three rows of the specimen retainer for the test using 0.1 volume per cent CI-2 in the fuel is shown in Figures 69, 70, and 71 and a summary of the number of specimens of each material and the hours of exposure is shown in Table 53. The revised schedule of specimen exposure for the test with the fuel additive still provides direct comparisons of



(a)
1 B-1900
2 MAR M-246
3 MAR M-200
4 IN-100
5 INCONEL 713C
6 UDIMET 700
7 IN-738
8 UDIMET 710

17 = MDC-1 COATED INCONEL 713C
18 = MDC-1 COATED UDIMET 700
19 = MDC-1 COATED IN-738
20 = MDC-1 COATED UDIMET 710
29 = MDC-9 COATED WI-52
30 = MDC-9 COATED MAR M-509
31 = MDC-9 COATED MAR M-302
32 = MDC-9 COATED X-40

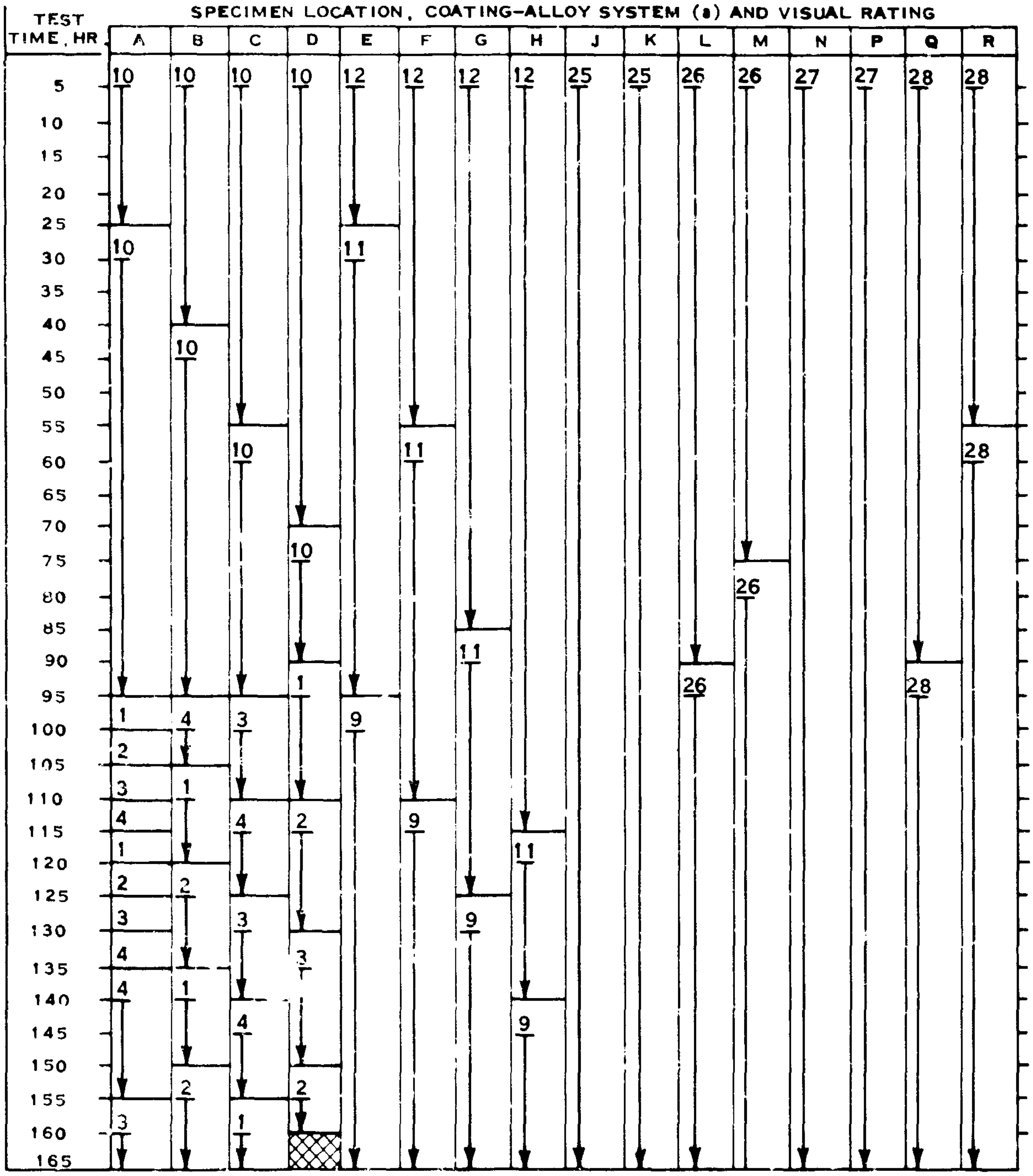
FIGURE 66
SCHEDULE OF SPECIMEN EXPOSURE FOR ROW 1
WITHOUT FUEL ADDITIVE



(a) 1 = B-1900
2 = MAR M-246
3 = MAR M-200
4 = IN-100
9 = WI-52
11 = MAR M-302
12 = X-40
A = AIRESIST 215

13 = MDC-1 COATED B-1900
14 = MDC-1 COATED MAR M-246
15 = MDC-1 COATED MAR M-200
16 = MDC-1 COATED IN-100
21 = MDC-9 COATED B-1900
22 = MDC-9 COATED MAR M-246
23 = MDC-9 COATED MAR M-200
24 = MDC-9 COATED IN -100

FIGURE 67
SCHEDULE OF SPECIMEN EXPOSURE FOR ROW 2
WITHOUT FUEL ADDITIVE



(a) 1 = B-1900
2 = MAR M-246
3 = MAR M-200
4 = IN-100
9 = WI-52
10 = MAR M-509
11 = MAR M-302
12 = X-40
25 = MDC-9 COATED INCONEL 713C
26 = MDC-9 COATED UDIMET 700
27 = MDC-9 COATED IN -738
28 = MDC-9 COATED UDIMET 710

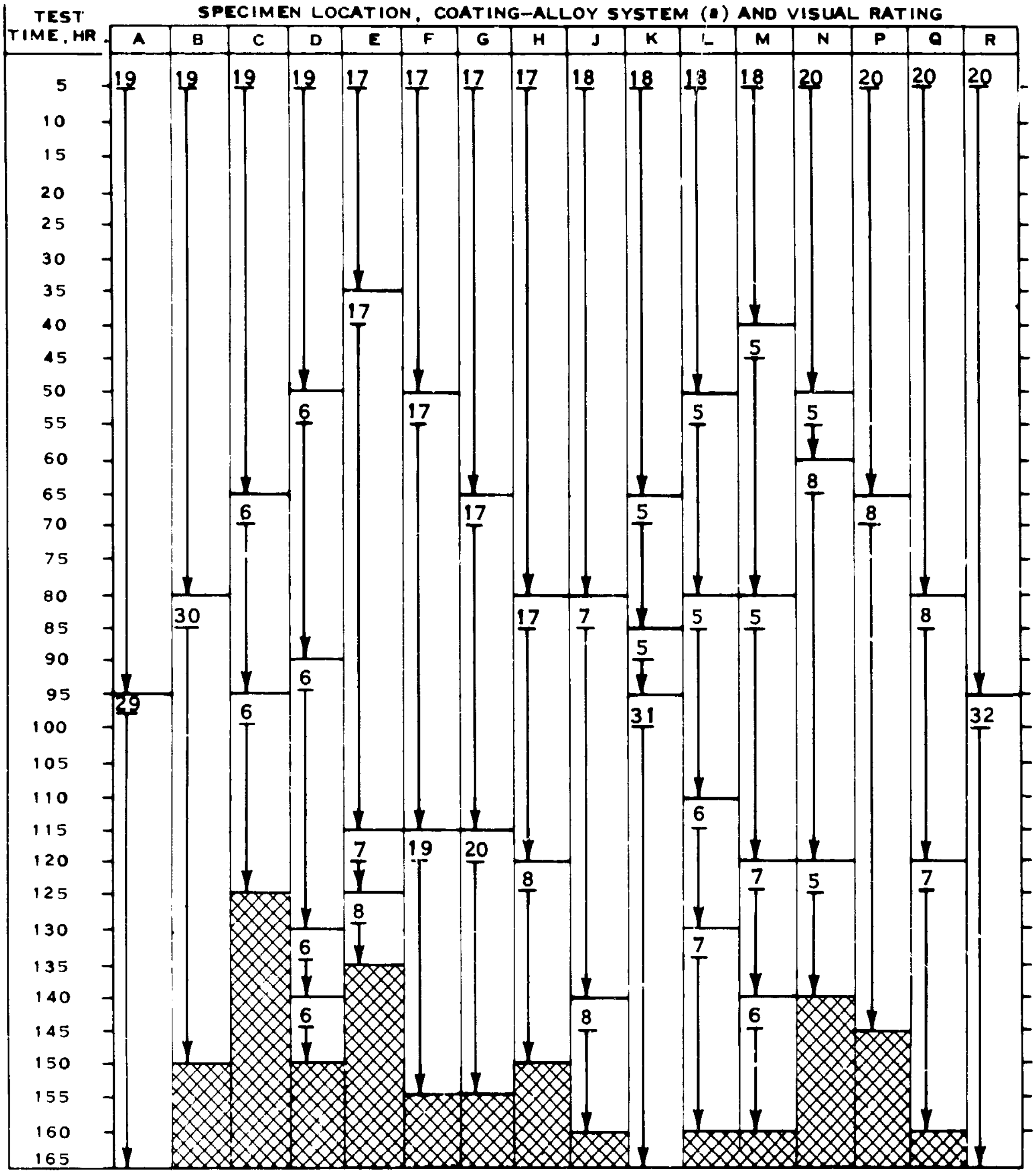
FIGURE 68
SCHEDULE OF SPECIMEN EXPOSURE FOR ROW 3
WITHOUT FUEL ADDITIVE

TABLE 52

SUMMARY OF SCHEDULE OF SPECIMEN EXPOSURE WITHOUT FUEL ADDITIVE

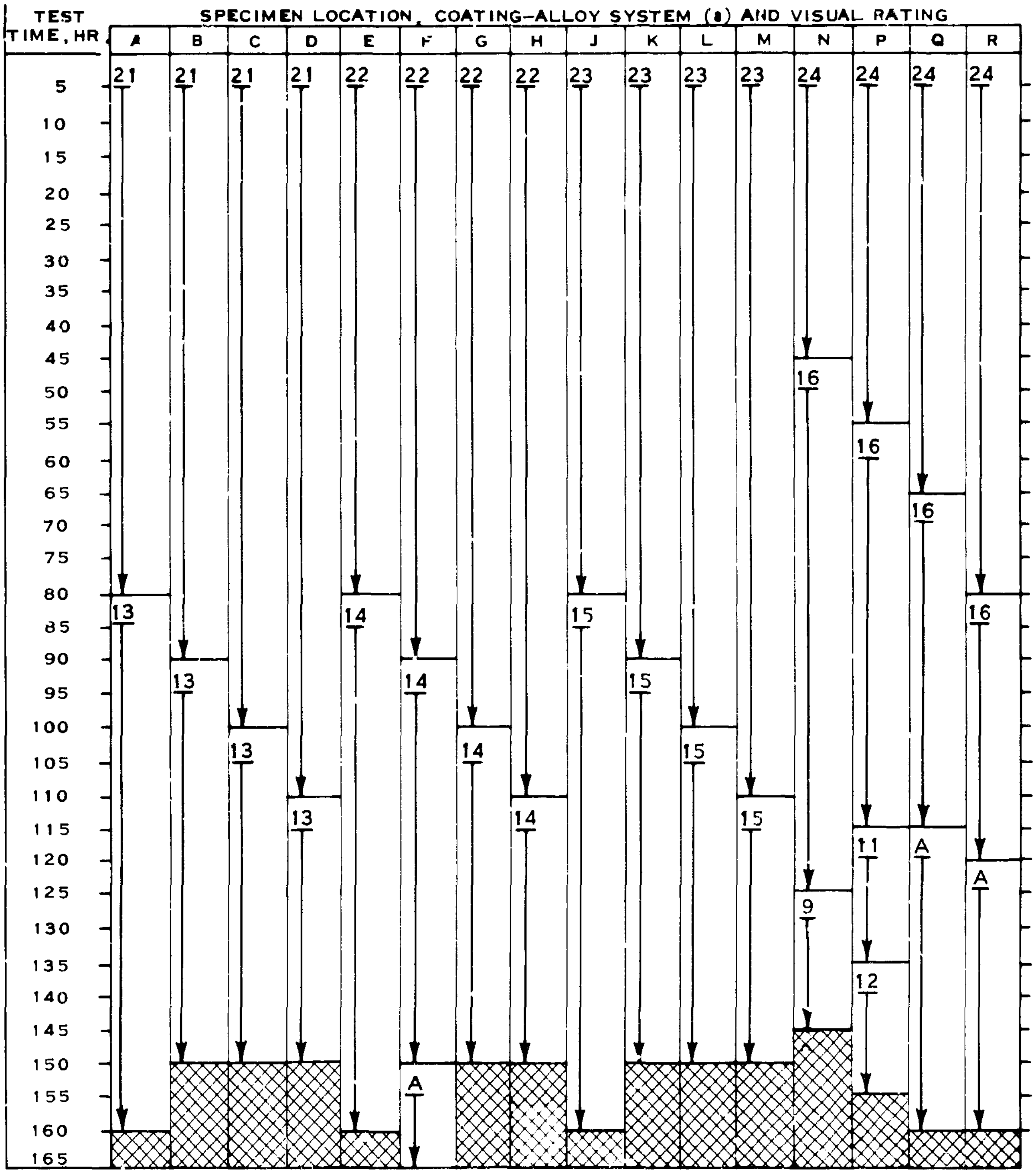
Exposure Time, hrs	Number of Specimens Exposed							
	B-1900	MM-246	MM-200	IN-100	I-713C	U-700	IN-738	U-710
	Bare Nickel-Base Superalloys							
5	6	6	4	6	...	...	...	...
10	1	1	1	1	2	2	1	1
15	6	6	6	6	...	...	...	...
20	1	1	1	1	2	2	1	1
30	...	...	...	...	2	2	1	1
40	...	...	...	...	2	2	1	1
60	...	...	...	...	...	...	1	1
80	...	...	...	...	...	...	...	1
	MDC-1 Coated Nickel-Base Superalloys							
35	...	...	...	...	1	...	...	...
40	1	1	1	1	1	1	1	1
50	1	1	1	1	2	1	1	1
60	1	1	1	1	...	...	...	...
65	...	...	...	...	2	1	1	1
80	1	1	1	1	2	1	1	1
95	...	...	...	...	...	...	1	1
	MDC-9 Coated Nickel-Base Superalloys							
45	...	...	...	1	...	...	...	...
55	...	...	...	1	...	...	...	1
65	...	...	...	1	...	...	...	...
75	...	...	...	...	...	2	...	1
80	1	1	1	1	...	...	...	...
90	1	1	1	...	...	2	...	1
100	1	1	1	...	...	...	...	...
110	1	1	1	...	...	...	...	1
165	...	...	...	...	2	...	2	...

Exposure Time, hrs	Bare Cobalt-Base Superalloys					MDC-9 Coated Cobalt-Base Superalloys			
	WI-52	MM-509	MM-302	X-40	AR-215	WI-52	MM-509	MM-302	X-40
15	...	...	...	...	1	...	...	...	...
20	1	1	1	1	...	...	...	...	...
25	1	1	1	1	...	...	...	...	...
40	1	2	1	...	1	...	...	...	...
45	...	...	...	...	1	...	...	...	...
55	1	2	1	1	...	...	...	...	...
70	1	2	1	...	...	1	1	1	1
85	...	...	...	1	...	...	...	...	...
115	...	...	...	1	...	...	...	...	...



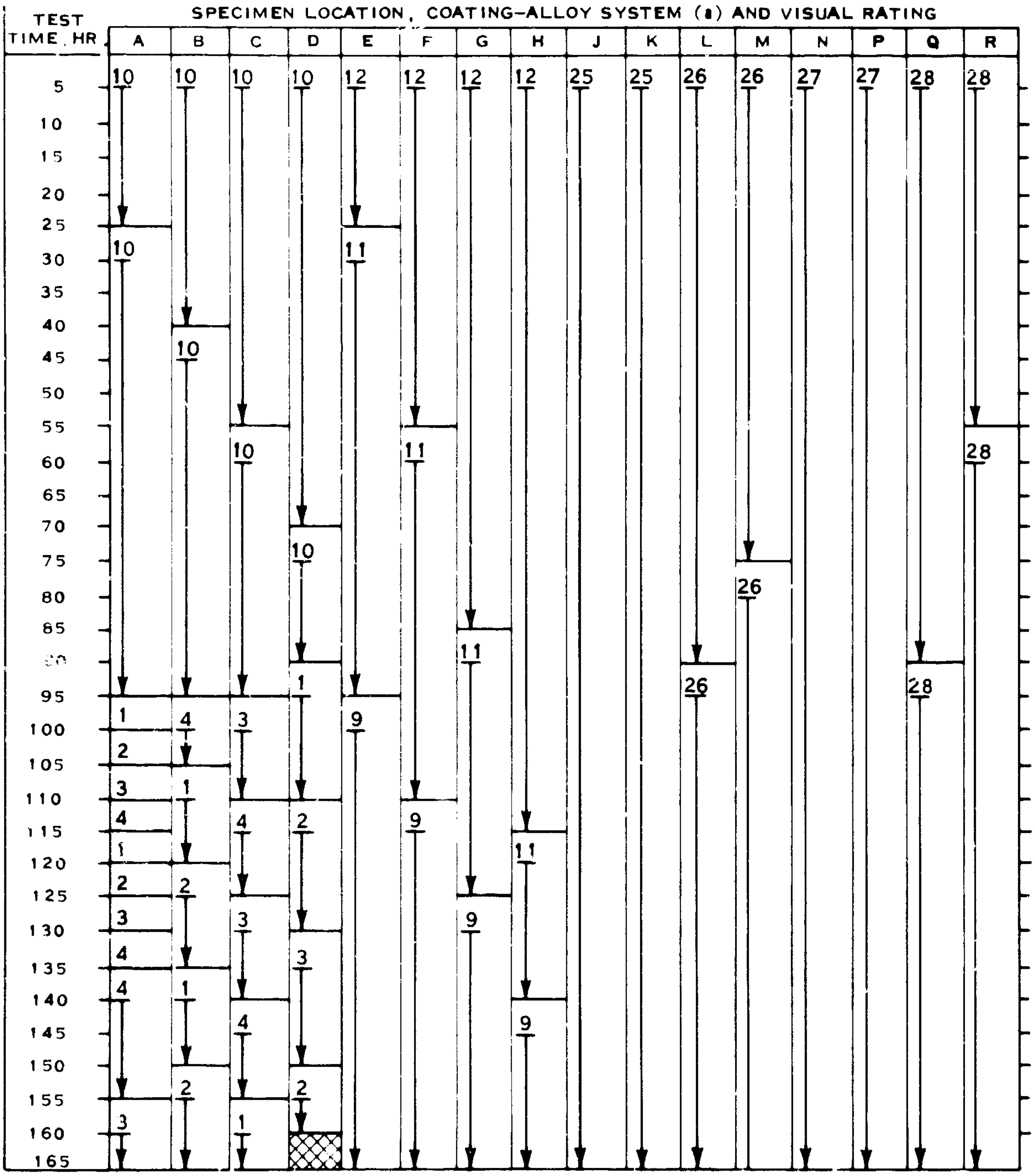
(a) 5 = INCONEL 713C
6 = UDIMET 700
7 = IN-738
8 = UDIMET 710
17 = MDC-1 COATED INCONEL 713C
18 = MDC-1 COATED UDIMET 700
19 = MDC-1 COATED IN-738
20 = MDC-1 COATED UDIMET 710
29 = MDC-9 COATED WI-52
30 = MDC-9 COATED MAR M-509
31 = MDC-9 COATED MAR M-302
32 = MDC-9 COATED X-40

FIGURE 69
SCHEDULE OF SPECIMEN EXPOSURE FOR ROW 1
WITH 0.1 VOLUME PERCENT CI-2



(a) 9 = WI-52
11 = MAR M-302
12 = X-40
A = AIRESIST 215
13 = MDC-1 COATED B-1900
14 = MDC-1 COATED MAR M-246
15 = MDC-1 COATED MAR M-200
16 = MDC-1 COATED IN-100
21 = MDC-9 COATED B-1900
22 = MDC-9 COATED MAR M-246
23 = MDC-9 COATED MAR M-200
24 = MDC-9 COATED IN-100

FIGURE 70
SCHEDULE OF SPECIMEN EXPOSURE FOR ROW 2
WITH 0.1 VOLUME PERCENT CI-2



(a) 1 = B-1900
2 = MAR M-246
3 = MAR M-200
4 = IN-100
9 = WI-52
10 = MAR M-509
11 = MAR M-302
12 = X-40
25 = MDC-9 COATED INCONEL 713C
26 = MDC-9 COATED UDIMET 700
27 = MDC-9 COATED IN -738
28 = MDC-9 COATED UDIMET 710

FIGURE 71
SCHEDULE OF SPECIMEN EXPOSURE FOR ROW 3
WITH 0.1 VOLUME PERCENT CI-2

TABLE 53

SUMMARY OF SCHEDULE OF SPECIMEN EXPOSURE WITH 0.1 VOLUME PER CENT CI-2

Exposure Time, hrs	Number of Specimens Exposed							
	B-1900	MM-246	MM-200	IN-100	I-713C	U-700	IN-738	U-710
	Bare Nickel-Base Superalloys							
5	2	2	2	2	...	...	...	...
10	1	1	1	1	2	2	1	1
15	2	2	2	2	...	...	...	...
20	1	1	1	1	2	2	1	1
30	...	...	...	...	2	2	1	1
40	...	...	...	...	2	2	1	1
60	...	...	...	...	...	...	1	1
80	...	...	...	...	...	...	...	1
	MDC-1 Coated Nickel-Base Superalloys							
35	...	...	...	...	1	...	...	...
40	1	1	1	1	1	1	1	1
50	1	1	1	1	2	1	1	1
60	1	1	1	1	...	...	...	...
65	...	...	...	...	2	1	1	1
80	1	1	1	1	2	1	1	1
95	...	...	...	...	...	...	1	1
	MDC-9 Coated Nickel-Base Superalloys							
45	...	...	...	1	...	...	...	...
55	...	...	...	1	...	...	...	1
65	...	...	...	1	...	...	...	...
75	...	...	...	...	...	2	...	1
80	1	1	1	1	...	...	...	...
90	1	1	1	...	...	2	...	1
100	1	1	1	...	...	...	...	...
110	1	1	1	...	...	...	...	1
165	...	...	...	...	2	...	2	...

Exposure Time, hrs	Bare Cobalt-Base Superalloys					MDC-9 Coated Cobalt-Base Superalloys			
	WI-52	MM-509	MM-302	X-40	AR-215	WI-52	MM-509	MM-302	X-40
15	...	...	...	...	1	...	...	...	...
20	1	1	1	1	...	...	...	...	...
25	1	1	1	1	...	...	...	...	...
40	1	2	1	...	1	...	...	...	...
45	...	...	...	...	1	...	...	...	...
55	1	2	1	1	...	...	...	...	...
70	1	2	1	...	...	1	1	1	1
85	...	...	...	1	...	...	...	...	...
115	...	...	...	1	...	...	...	...	...

superalloys and superalloy-coating systems since the revision merely advances the time for exposure of some specimens in the test with the fuel additive without changing the row or position in the row for a specimen.

11. APPENDIX 4

(Test Data)

11.1. Visual Ratings of Specimens

The 48 specimens in the retainer were examined after each five hours of exposure using a binocular microscope (10X) and ratings were assigned to the specimens using the rating scale shown in Table 50 (Appendix 3). Ratings of the specimens exposed in the test with 0.040 weight per cent sulfur and no additive in the fuel are shown in Figures 72, 73, and 74 and ratings of specimens exposed with 0.040 weight per cent sulfur and 0.1 volume per cent CI-2 in the fuel are shown in Figures 75, 76, and 77. Ratings of the specimens exposed with CI-2 in the fuel are doubtful values because of the heavy deposit on the specimens that tended to build-up and then flake-off.

11.2. Weight of Surface Scale

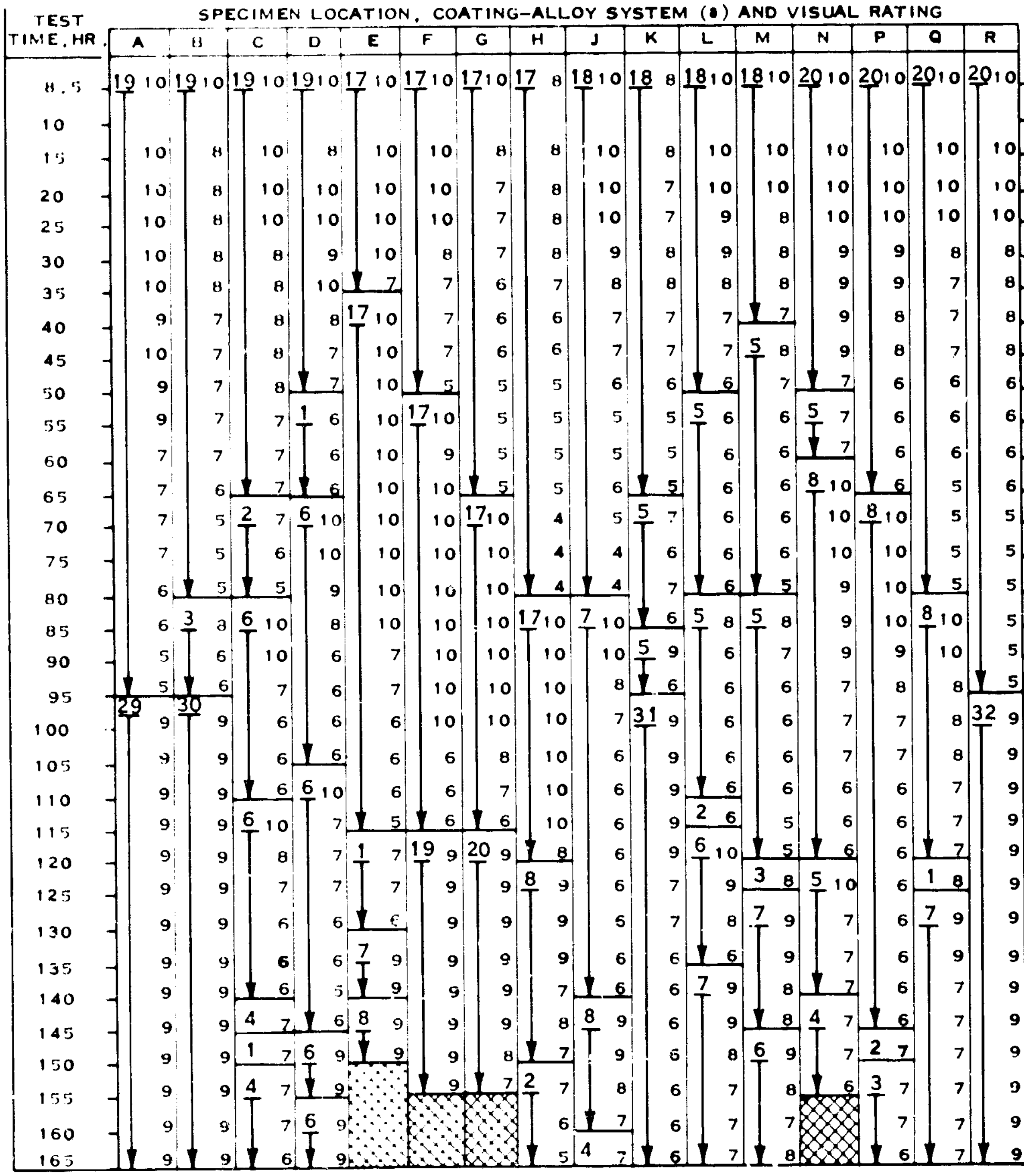
Each specimen was weighed after it was removed from the specimen retainer following exposure. A sample of surface scale was removed by scraping with a stainless-steel spatula and the specimen was then electro-cleaned. The difference between the weight of the specimen after exposure and after electro-cleaning was recorded as weight of surface scale. The weight of surface scale and the weight of surface scale per unit area of new specimen is recorded in Table 54 for each specimen exposed with 0.040 weight per cent sulfur in fuel and in Table 55 for each specimen exposed with 0.040 weight per cent sulfur and 0.1 volume per cent CI-2 in the fuel.

11.3. Metal Weight-Loss

The weight-loss of a test specimen was calculated as the difference in weight of the specimen before exposure and the weight of the exposed specimen after electro-cleaning. The weight-loss and the weight-loss per unit area (based on area of new specimens) are shown in Table 56 for specimens exposed with 0.040 weight per cent sulfur in fuel and in Table 57 for specimens exposed with 0.040 weight per cent sulfur and 0.1 volume per cent CI-2 in the fuel.

11.4. Metallographic-Penetration Data

Each test specimen was sectioned at the location of average visual attack and maximum visual attack and measurements of surface loss and maximum attack were made using the technique described in Appendix 3 (Section 10.3.) of this report. Measurements of surface loss for each specimen exposed in the base-line test are shown in Table 58 and measurements of specimens from the fuel-additive test are shown in Table 59. Measurements of maximum attack on each specimen from the base-line test are shown in Table 60 and for the fuel-additive test in Table 61.



(a)

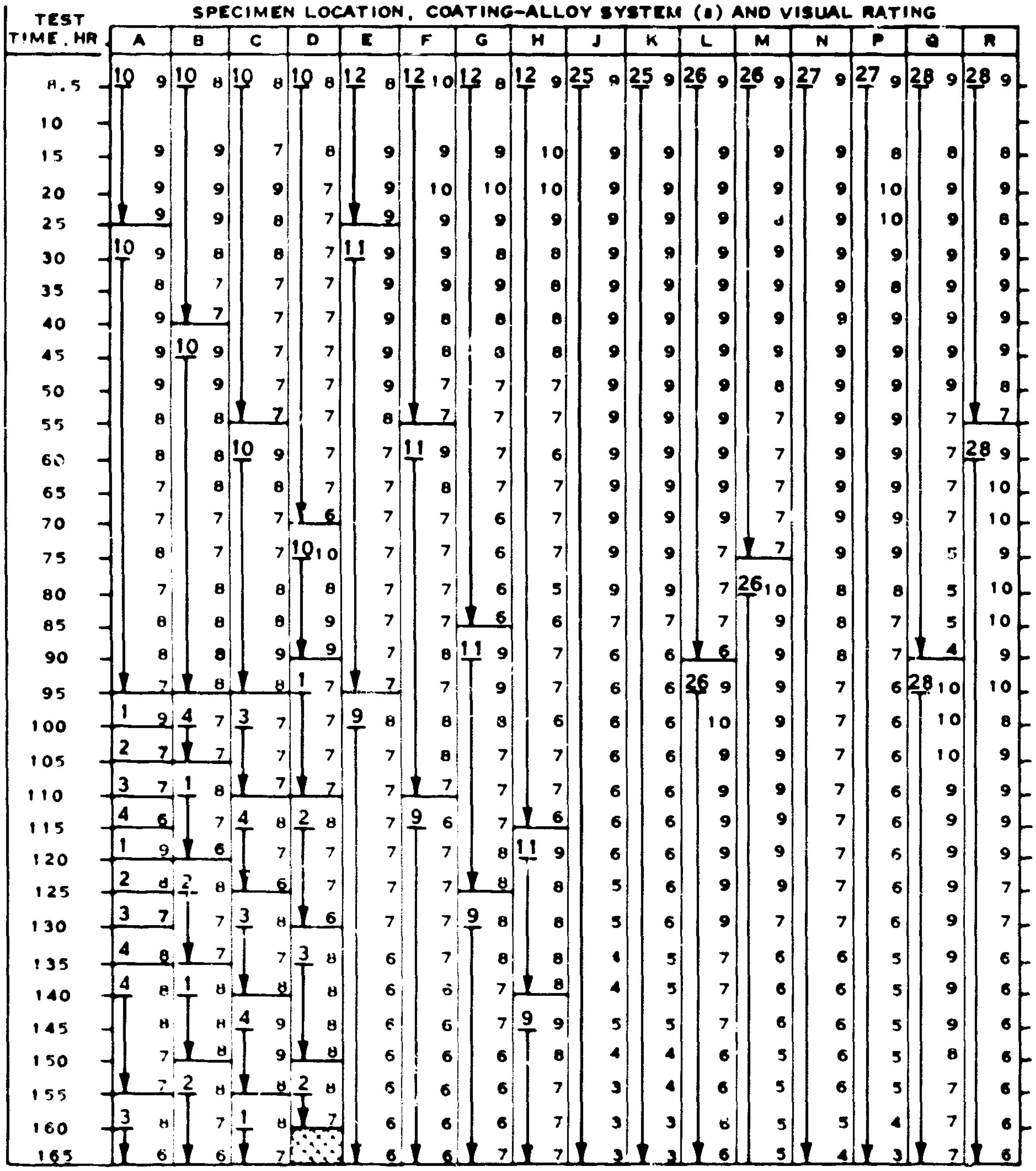
1	B-1900	17 =	MDC-1 COATED INCONEL 713C
2	MAR M-246	18 =	MDC-1 COATED UDIMET 700
3	MAR M-200	19 =	MDC-1 COATED IN-738
4	IN-100	20 =	MDC-1 COATED UDIMET 710
5	INCONEL 713C	29 =	MDC-9 COATED WI-52
6	UDIMET 700	30 =	MDC-9 COATED MAR M-509
7	IN-738	31 =	MDC-9 COATED MAR M-302
8	UDIMET 710	32 =	MDC-9 COATED X-40

FIGURE 72
SPECIMEN EXPOSURE IN ROW 1 WITHOUT FUEL ADDITIVE

TEST TIME, HR	SPECIMEN LOCATION, COATING-ALLOY SYSTEM (a) AND VISUAL RATING															
	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q	R
8.5	(21) 10	(21) 10	(21) 10	(21) 10	(22) 10	(22) 10	(22) 10	(22) 10	(23) 9	(23) 9	(23) 9	(23) 9	(24) 9	(24) 9	(24) 9	(24) 9
10																
15	10	10	10	10	10	10	10	10	9	9	9	9	9	9	7	9
20	9	8	9	10	9	9	10	9	9	10	10	10	10	10	9	8
25	10	8	9	10	9	9	10	10	10	10	10	9	9	9	8	8
30	9	9	9	8	9	9	10	9	9	9	9	9	9	9	8	8
35	9	8	8	10	9	9	9	9	8	8	9	9	9	9	8	8
40	9	9	9	9	9	9	9	9	9	9	9	9	9	9	8	8
45	9	8	9	9	9	9	9	9	9	8	9	9	8	7	6	7
50	9	8	9	9	9	9	9	9	8	9	9	9	(1) 7	6	6	6
55	9	8	9	9	9	9	9	9	8	8	9	9	(16) 10	6	5	5
60	9	9	9	9	9	9	9	9	8	8	9	9	10	(2) 7	4	5
65	9	8	9	9	9	9	9	9	8	9	9	9	10	(16) 10	4	4
70	9	9	9	8	9	9	9	9	8	8	9	9	9	9	(3) 6	4
75	9	9	9	9	9	9	9	9	7	9	9	9	10	10	(16) 10	3
80	9	9	9	9	9	9	9	9	6	9	8	9	10	8	10	3
85	(1) 8	9	9	9	(14) 9	9	9	9	(15) 9	8	8	8	7	9	9	(4) 8
90	(13) 10	9	9	9	9	9	9	9	9	9	8	8	6	7	8	(16) 10
95	10	(2) 8	8	8	10	(14) 10	9	9	10	(15) 9	7	8	5	6	6	10
100	9	6	8	8	9	10	9	9	9	9	7	7	5	5	7	9
105	9	6	(3) 7	9	9	10	(14) 10	9	9	9	(15) 10	7	5	6	6	9
110	8	(13) 9	7	9	9	9	9	9	9	9	9	6	5	5	6	7
115	9	9	5	(4) 7	9	9	9	(14) 9	9	9	9	(15) 9	4	5	5	7
120	9	9	(13) 9	6	9	9	9	9	8	9	9	9	3	4	4	6
125	8	10	10	6	9	9	9	9	7	8	8	9	3	(11) 9	(A) 9	6
130	9	9	9	(13) 9	9	9	9	9	7	7	7	9	3	8	9	(A) 9
135	9	8	9	8	8	9	9	8	6	6	7	9	(1) 7	8	8	9
140	9	8	9	8	7	8	9	7	6	5	6	9	7	8	9	9
145	9	7	9	7	7	8	9	6	5	4	6	7	6	(12) 9	8	8
150	7	7	9	7	7	8	7	6	4	4	6	7	(9) 8	9	8	8
155	6	6	9	6	6	(A) 9	(1) 7	(4) 7	5	(2) 6	(3) 8	(4) 9	8	9	8	8
160	6	6	9	6	6	9	6		5	7	8	7	7	9	8	8
165	6	6	7	6	(2) 7	9	7			6	6	6	7		8	8

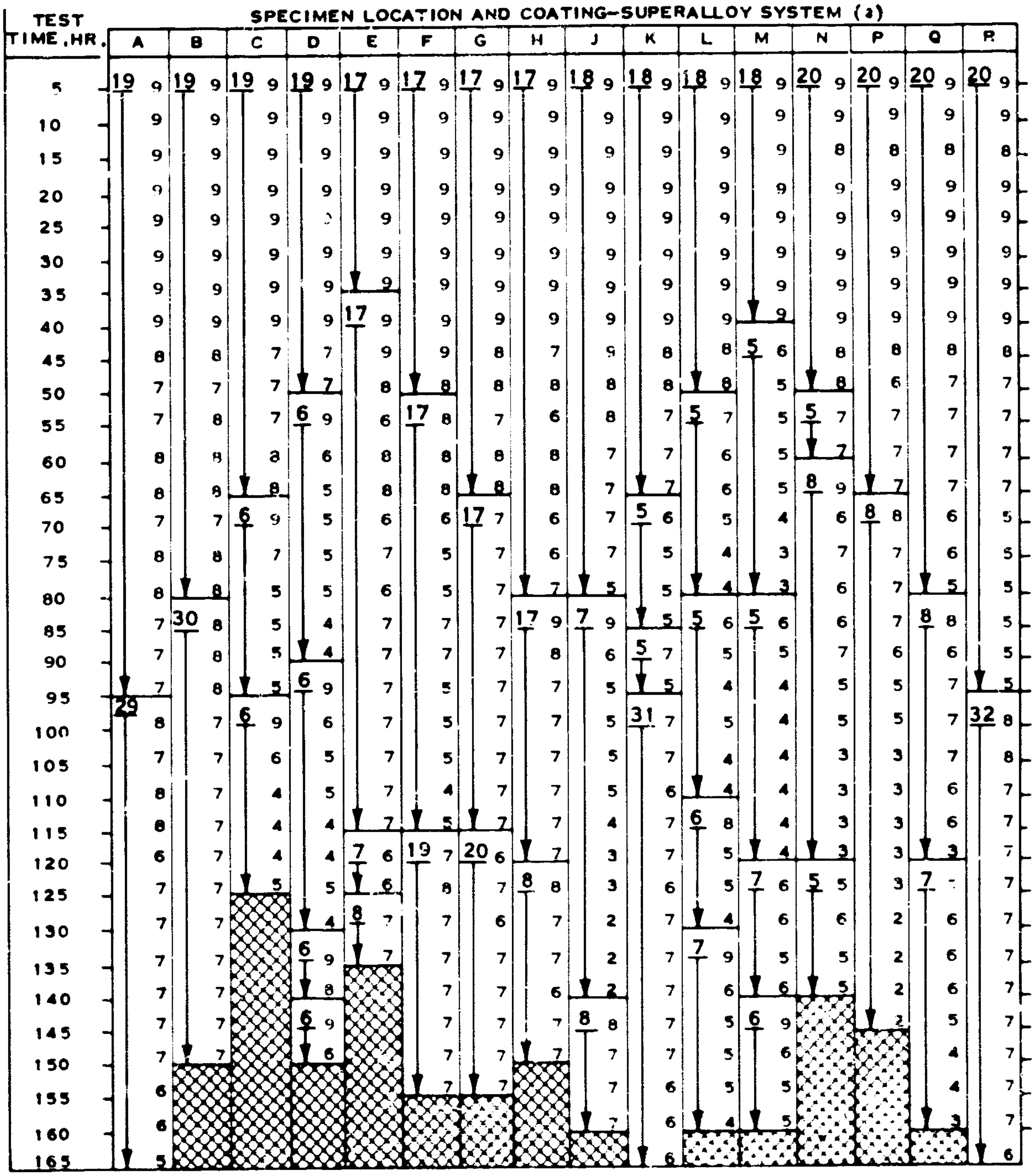
(a) 1 = B-1900
2 = MAR M-246
3 = MAR M-200
4 = IN-100
9 = WI-52
11 = MAR M-302
12 = X-40
A = AIRESIST 215
13 = MDC-1 COATED B-1900
14 = MDC-1 COATED MAR M-246
15 = MDC-1 COATED MAR M-200
16 = MDC-1 COATED IN-100
21 = MDC-9 COATED B-1900
22 = MDC-9 COATED MAR M-246
23 = MDC-9 COATED MAR M-200
24 = MDC-9 COATED IN-100

FIGURE 73
SPECIMEN EXPOSURE IN ROW 2 WITHOUT FUEL ADDITIVE



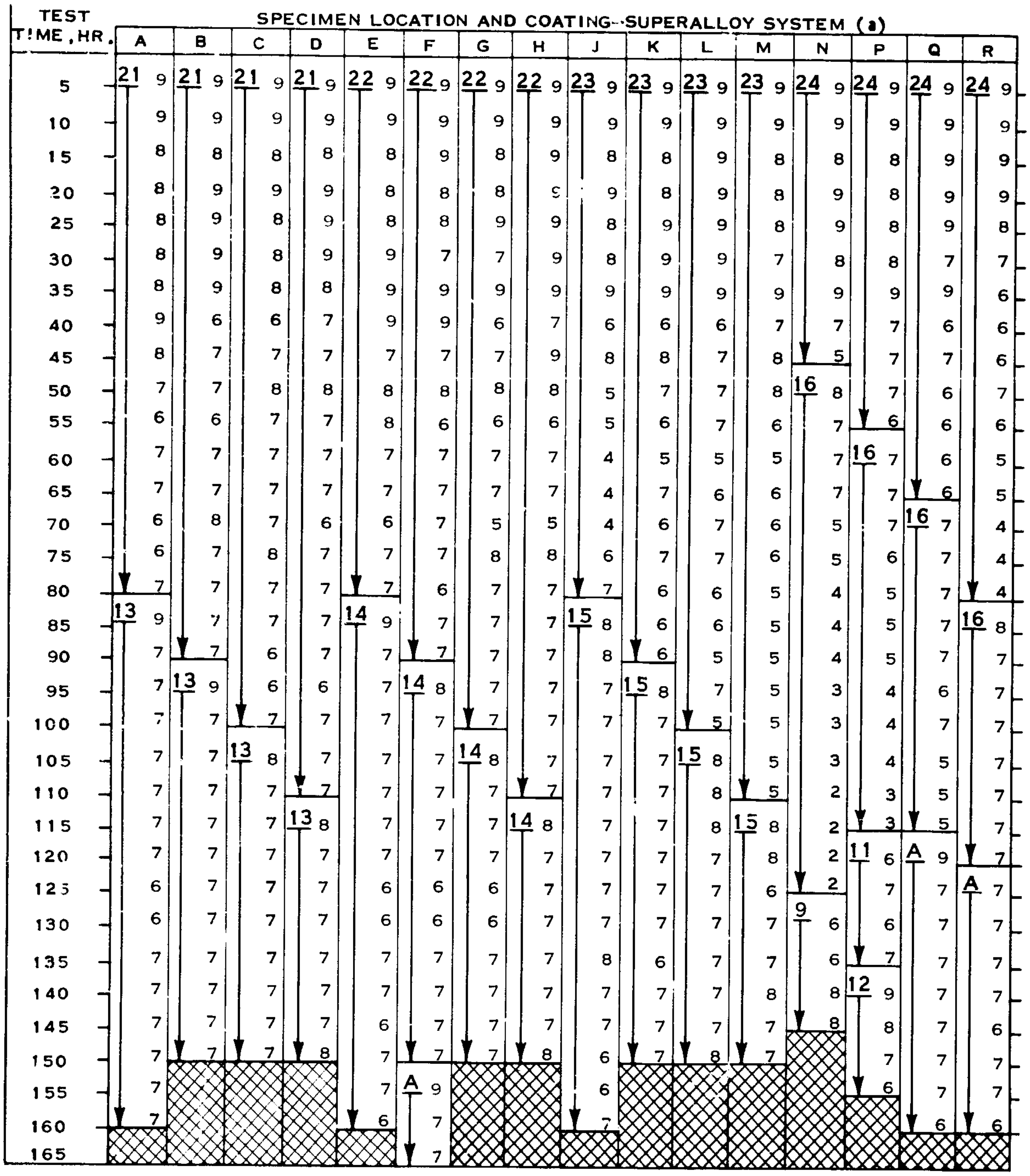
(a) 1 B-1900
2 MAR M-246
3 MAR M-200
4 IN-100
9 WI-52
10 MAR M-509
11 = MAR M-302
12 = X-40
25 = MDC-9 COATED INCONEL 713C
26 = MDC-9 COATED UDIMET 700
27 = MDC-9 COATED IN-738
28 = MDC-9 COATED UDIMET 710

FIGURE 74
SPECIMEN EXPOSURE IN ROW 3 WITHOUT FUEL ADDITIVE



(a) 5 = INCONEL 713C
6 = UDIMET 700
7 = IN-738
8 = UDIMET 710
17 = MDC-1 COATED INCONEL 713C
18 = MDC-1 COATED UDIMET 700
19 = MDC-1 COATED IN-738
20 = MDC-1 COATED UDIMET 710
29 = MDC-9 COATED WI-52
30 = MDC-9 COATED MAR M-509
31 = MDC-9 COATED MAR M-302
32 = MDC-9 COATED X-40

FIGURE 75
SPECIMEN EXPOSURE IN ROW 1 WITH
0.1 VOLUME PER CENT CI-2



(a) 9 = WI-52
11 = MAR M-302
12 = X-40
A = AIRESIST 215
13 = MDC-1 COATED B-1900
14 = MDC-1 COATED MAR M-246
15 = MDC-1 COATED MAR M-200
16 = MDC-1 COATED IN-100
21 = MDC-9 COATED B-1900
22 = MDC-9 COATED MAR M-246
23 = MDC-9 COATED MAR M-200
24 = MDC-9 COATED IN-100

FIGURE 76
SPECIMEN EXPOSURE IN ROW 2 WITH 0.1 VOLUME PER CENT CI-2

SPECIMEN LOCATION AND COATING–SUPERALLOY SYSTEM (a)

TEST TIME, HR.	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q	R
5	10 9	10 9	10 9	10 9	12 9	12 9	12 9	12 9	25 9	25 9	26 9	26 9	27 9	27 9	28 9	28 9
10	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
15	9	9	9	9	9	9	9	9	8	8	8	8	8	9	8	8
20	9	9	9	9	9	9	9	9	9	9	8	8	9	8	8	8
25	9	8	7	7	8	9	9	9	8	8	8	7	8	7	7	8
30	10 7	8	6	7	11 7	8	9	6	8	9	8	6	7	9	8	7
35	9	9	6	6	9	5	6	6	8	7	7	6	7	9	9	6
40	6	5	6	7	6	6	6	6	6	7	6	6	6	7	7	6
45	9	10 9	7	7	7	6	5	6	6	6	5	6	7	7	6	6
50	6	7	7	6	7	6	6	5	5	6	6	7	5	5	7	6
55	6	7	6	5	7	5	6	5	7	7	6	7	7	7	6	6
60	7	8	10 9	6	6	11 9	7	6	6	6	7	6	6	5	5	28 8
65	7	8	9	6	6	9	7	6	6	6	7	6	6	6	5	7
70	6	6	7	5	5	6	5	4	7	7	6	6	6	6	5	7
75	6	6	7	10 8	5	6	4	4	7	7	6	6	7	7	5	7
80	5	6	7	7	7	6	6	5	7	7	5	26 7	8	7	5	7
85	6	7	7	7	6	6	5	5	7	7	5	7	7	7	5	7
90	7	7	7	7	6	7	11 8	6	7	7	5	7	7	7	5	6
95	7	7	6	1 6	6	7	8	6	7	7	26 8	7	7	7	28 7	7
100	1 7	4 8	3 6	5	9 8	6	8	5	7	7	8	8	7	7	8	7
105	2 6	5	5	5	5	6	7	6	7	7	8	7	7	6	7	7
110	3 6	1 6	6	5	6	7	7	4	7	7	7	7	7	6	7	7
115	4 6	5	4 7	2 6	7	9 6	7	3	7	7	7	7	7	5	7	7
120	1 6	5	6	6	7	6	7	11 8	7	7	7	7	7	5	7	7
125	2 6	2 6	6	6	7	6	6	7	6	6	7	6	6	4	7	6
130	3 6	5	3 5	4	7	6	9 5	6	5	7	7	5	7	4	6	6
135	4 5	3	4	3 5	7	7	5	7	7	7	8	7	7	4	7	7
140	4 6	1 6	4	5	7	7	6	6	7	6	8	7	6	5	7	6
145	4	4	4 6	5	7	7	8	9 7	6	7	7	7	6	5	7	6
150	4	5	6	6	7	7	8	6	7	7	6	7	7	5	7	7
155	5	2 6	6	2 6	7	7	8	6	7	7	7	7	7	3	6	6
160	3 5	5	1 6	5	7	6	6	6	6	7	6	6	6	4	7	7
165	5	5	6		6	6	6	6	6	7	6	7	6	3	7	7

(a) 1 = B-1900
2 = MAR M-246
3 = MAR M-200
4 = IN-100
9 = WI-52
10 = MAR M-509
11 = MAR M-302
12 = X-40
25 = MDC-9 COATED INCONEL 713C
26 = MDC-9 COATED UDIMET 700
27 = MDC-9 COATED IN-738
28 = MDC-9 COATED UDIMET 710

FIGURE 77
SPECIMEN EXPOSURE IN ROW 3 WITH 0.1 VOLUME PER CENT CI-2

TABLE 54

WEIGHT OF SURFACE SCALE ON TEST SPECIMENS
(0.040 Weight Per Cent Sulfur in Fuel)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Weight of Surface Scale	
							mg	mg/cm^2
B-1900	None	14	1C	145	150	5	42.4	5.46
B-1900	None	11	1Q	120	125	5	38.1	4.91
B-1900	None	5	2A	80	85	5	49.9	6.43
B-1900	None	3	2N	45	50	5	65.5	8.44
B-1900	None	7	3A	95	100	5	28.2	3.63
B-1900	None	10	3A	115	120	5	19.7	2.54
B-1900	None	16	3C	155	165	10	69.3	8.93
B-1900	None	4	1D	50	65	15	126.2	16.26
B-1900	None	9	1E	115	130	15	61.9	7.98
B-1900	None	15	2G	150	165	15	63.9	8.23
B-1900	None	12	2N	130	145	15	63.7	8.21
B-1900	None	8	3B	105	120	15	113.1	14.57
B-1900	None	13	3B	135	150	15	48.5	6.25
B-1900	None	6	3D	90	110	20	179.2	23.09
B-1900	MDC-1	131	2D	125	165	40	71.4	9.20
B-1900	MDC-1	130	2C	115	165	50	43.1	5.55
B-1900	MDC-1	129	2B	105	165	60	55.3	7.13
B-1900	MDC-1	128	2A	85	165	80	46.3	5.97
B-1900	MDC-9	180	2A	0	80	80	29.4	3.79
B-1900	MDC-9	181	2B	0	90	90	23.8	3.07
B-1900	MDC-9	182	2C	0	100	100	21.8	2.81
B-1900	MDC-9	183	2D	0	110	110	31.6	4.07
Mar M-246	None	23	1L	110	115	5	104.4	13.45
Mar M-246	None	27	1P	145	150	5	43.6	5.62
Mar M-246	None	32	2E	160	165	5	43.3	5.58
Mar M-246	None	19	2P	55	60	5	107.5	13.85
Mar M-246	None	22	3A	100	105	5	91.4	11.78
Mar M-246	None	25	3A	120	125	5	62.3	8.03
Mar M-246	None	31	3D	150	160	10	75.9	9.78
Mar M-246	None	20	1C	65	80	15	116.8	15.05
Mar M-246	None	28	1H	150	165	15	79.0	10.18
Mar M-246	None	21	2B	90	105	15	212.7	27.41
Mar M-246	None	29	2K	150	165	15	71.4	9.20
Mar M-246	None	26	3B	120	135	15	114.9	14.81
Mar M-246	None	30	3B	150	165	15	126.4	16.29
Mar M-246	None	24	3D	110	130	20	162.5	20.94

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

TABLE 54 (Cont'd)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Weight of Surface Scale mg	mg/cm^2
Mar M-246	MDC-1	137	2H	110	150	40	79.7	10.27
Mar M-246	MDC-1	136	2G	100	150	50	35.6	4.59
Mar M-246	MDC-1	135	2F	90	150	60	64.9	8.36
Mar M-246	MDC-1	134	2E	80	160	80	31.7	4.08
Mar M-246	MDC-9	186	2E	0	80	80	29.7	3.83
Mar M-246	MDC-9	187	2F	0	90	90	28.6	3.68
Mar M-246	MDC-9	188	2G	0	100	100	23.1	2.98
Mar M-246	MDC-9	189	2H	0	110	110	27.6	3.56
Mar M-200	None	40	1M	120	125	5	93.3	12.02
Mar M-200	None	35	2Q	65	70	5	120.3	15.50
Mar M-200	None	39	3A	105	110	5	131.6	16.96
Mar M-200	None	41	3A	125	130	5	89.9	11.58
Mar M-200	None	46	3A	155	165	10	101.5	13.08
Mar M-200	None	36	1B	80	95	15	172.3	22.20
Mar M-200	None	44	1P	150	165	15	133.5	17.20
Mar M-200	None	38	2C	100	115	15	236.9	30.53
Mar M-200	None	45	2L	150	165	15	99.1	12.77
Mar M-200	None	37	3C	95	110	15	215.4	27.76
Mar M-200	None	42	3C	125	140	15	128.6	16.57
Mar M-200	None	43	3D	130	150	20	110.7	14.26
Mar M-200	MDC-1	143	2M	110	150	40	32.9	4.24
Mar M-200	MDC-1	142	2L	100	150	50	49.1	6.33
Mar M-200	MDC-1	141	2K	90	150	60	45.5	5.86
Mar M-200	MDC-1	140	2J	80	160	80	46.6	6.00
Mar M-200	MDC-9	192	2J	0	80	80	41.1	5.30
Mar M-200	MDC-9	193	2K	0	90	90	42.5	5.48
Mar M-200	MDC-9	194	2L	0	100	100	35.6	4.59
Mar M-200	MDC-9	195	2M	0	110	110	39.4	5.08
IN-100	None	56	1C	140	145	5	43.4	5.59
IN-100	None	62	1J	160	165	5	41.9	5.40
IN-100	None	60	2H	150	155	5	46.4	5.98
IN-100	None	49	2R	80	85	5	33.6	4.33
IN-100	None	52	3A	110	115	5	80.8	10.41
IN-100	None	54	3A	130	135	5	41.1	5.30
IN-100	None	50	3B	95	105	10	99.3	12.80

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

TABLE 54 (Cont'd)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Weight of Surface Scale mg	mg/cm^2
IN-100	None	59	1C	150	165	15	66.2	8.53
IN-100	None	57	1N	140	155	15	89.1	11.48
IN-100	None	51	2D	110	125	15	85.1	10.97
IN-100	None	61	2M	150	165	15	8.1	1.04
IN-100	None	53	3C	110	125	15	116.1	14.96
IN-100	None	58	3C	140	155	15	79.8	10.28
IN-100	None	55	3A	135	155	20	76.4	9.84
IN-100	MDC-1	149	2R	85	125	40	40.9	5.27
IN-100	MDC-1	148	2Q	70	120	50	35.9	4.63
IN-100	MDC-1	147	2P	60	120	60	39.5	5.09
IN-100	MDC-1	146	2N	50	130	80	46.7	6.02
IN-100	MDC-9	198	2N	0	45	45	19.0	2.45
IN-100	MDC-9	199	2P	0	55	55	48.1	6.20
IN-100	MDC-9	200	2Q	0	65	65	206.0	26.54
IN-100	MDC-9	201	2R	0	80	80	44.9	5.79
Inconel 713C	None	71	1K	85	95	10	78.1	10.06
Inconel 713C	None	67	1N	50	60	10	92.0	11.86
Inconel 713C	None	68	1K	65	85	20	75.0	9.66
Inconel 713C	None	72	1N	120	140	20	93.6	12.06
Inconel 713C	None	66	1L	50	80	30	81.1	10.45
Inconel 713C	None	69	1L	80	110	30	113.8	14.66
Inconel 713C	None	65	1M	40	80	40	75.4	9.72
Inconel 713C	None	70	1M	80	120	40	88.7	11.43
Inconel 713C	MDC-1	152	1E	0	35	35	22.9	2.95
Inconel 713C	MDC-1	159	1H	80	120	40	21.8	2.81
Inconel 713C	MDC-1	153	1F	0	50	50	35.3	4.55
Inconel 713C	MDC-1	158	1G	65	115	50	43.7	5.63
Inconel 713C	MDC-1	154	1G	0	65	65	50.7	6.53
Inconel 713C	MDC-1	157	1F	50	115	65	40.4	5.21
Inconel 713C	MDC-1	155	1H	0	80	80	41.5	5.35
Inconel 713C	MDC-1	156	1E	35	115	80	50.0	6.44
Inconel 713C	MDC-9	204	3J	0	165	165	47.8	6.16
Inconel 713C	MDC-9	205	3K	0	165	165	50.4	6.49
Udimet 700	None	80	1D	145	155	10	42.4	5.46
Udimet 700	None	82	1D	155	165	10	39.0	5.03
Udimet 700	None	79	1L	115	135	20	78.5	10.12
Udimet 700	None	81	1M	145	165	20	81.7	10.53

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

TABLE 54 (Cont'd)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Weight of Surface Scale mg	Weight of Surface Scale mg/cm^2
Udimet 700	None	76	1C	80	110	30	147.0	18.94
Udimet 700	None	78	1C	110	140	30	105.4	13.58
Udimet 700	None	75	1D	65	105	40	157.2	20.26
Udimet 700	None	77	1D	105	145	40	129.7	16.71
Udimet 700	MDC-1	165	1M	0	40	40	46.3	5.97
Udimet 700	MDC-1	164	1L	0	50	50	54.8	7.06
Udimet 700	MDC-1	163	1K	0	65	65	87.5	11.28
Udimet 700	MDC-1	162	1J	0	80	80	98.7	12.72
Udimet 700	MDC-9	230	3L	90	165	75	59.0	7.60
Udimet 700	NDC-9	209	3M	0	75	75	54.1	6.97
Udimet 700	MDC-9	208	3L	0	90	90	51.4	6.62
Udimet 700	MDC-9	231	3M	75	165	90	59.3	7.64
IN-738	None	88	1E	130	140	10	49.1	6.33
IN-738	None	86	1M	125	145	20	83.8	10.80
IN-738	None	89	1L	135	165	30	87.2	11.24
IN-738	None	87	1Q	125	165	40	94.0	12.11
IN-738	None	85	1J	80	140	60	143.3	18.47
IN-738	MDC-1	237	1F	115	155	40	26.5	3.42
IN-738	MDC-1	171	1D	0	50	50	38.7	4.99
IN-738	MDC-1	170	1C	0	65	65	83.0	10.70
IN-738	MDC-1	169	1B	0	80	80	115.3	14.86
IN-738	MDC-1	168	1A	0	95	95	37.8	4.87
IN-738	MDC-9	212	3N	0	165	165	57.4	7.40
IN-738	MDC-9	213	3P	0	165	165	62.8	8.09
Udimet 710	None	96	1E	140	150	10	42.4	5.46
Udimet 710	None	97	1J	140	160	20	67.2	8.66
Udimet 710	None	95	1H	120	150	30	91.7	11.82
Udimet 710	None	94	1Q	80	120	40	191.8	24.72
Udimet 710	None	92	1N	60	120	60	210.4	27.11
Udimet 710	None	93	1P	65	145	80	176.5	22.74
Udimet 710	MDC-1	238	1G	115	155	40	33.2	4.28
Udimet 710	MDC-1	174	1N	0	50	50	51.3	6.61
Udimet 710	MDC-1	175	1P	0	65	65	150.7	19.42
Udimet 710	MDC-1	176	1Q	0	80	80	97.5	12.56
Udimet 710	MDC-1	177	1R	0	95	95	42.6	5.49

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row. Letter = Position in Row.

TABLE 54 (Cont'd)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Weight of Surface Scale mg	Weight of Surface Scale mg/cm²
Udimet 710	MDC-9	217	3R	0	55	55	65.3	8.41
Udimet 710	MDC-9	227	3Q	90	165	75	43.5	5.60
Udimet 710	MDC-9	216	3Q	0	90	90	181.9	23.44
Udimet 710	MDC-9	226	3R	55	165	110	61.6	7.94
WI-52	None	234	2N	145	165	20	120.5	15.53
WI-52	None	103	3H	140	165	25	164.5	21.20
WI-52	None	102	3G	125	165	40	189.6	24.43
WI-52	None	101	3F	110	165	55	215.0	27.70
WI-52	None	100	3E	95	165	70	251.2	32.37
WI-52	MDC-9	240	1A	95	165	70	28.1	3.62
Mar M-509	None	113	3D	70	90	20	70.1	9.03
Mar M-509	None	106	3A	0	25	25	179.7	23.16
Mar M-509	None	107	3B	0	40	40	138.3	17.82
Mar M-509	None	112	3C	55	95	40	142.8	18.40
Mar M-509	None	108	3C	0	55	55	167.4	21.57
Mar M-509	None	111	3B	40	95	55	134.9	17.38
Mar M-509	None	109	3D	0	70	70	149.9	19.32
Mar M-509	None	110	3A	25	95	70	162.4	20.93
Mar M-509	MDC-9	241	1B	95	165	70	62.0	7.99
Mar M-302	None	235	2P	120	140	20	101.2	13.04
Mar M-302	None	119	3H	115	140	25	139.5	17.98
Mar M-302	None	118	3G	85	125	40	171.5	22.10
Mar M-302	None	117	3F	55	110	55	208.8	26.91
Mar M-302	None	116	3E	25	95	70	160.3	20.66
Mar M-302	MDC-9	242	1K	95	165	70	94.5	12.18
X-40	None	236	2P	140	160	20	99.0	12.76
X-40	None	122	3E	0	25	25	96.2	12.40
X-40	None	123	3F	0	55	55	131.1	16.89
X-40	None	124	3G	0	85	85	191.6	24.69
X-40	None	125	3H	0	115	115	341.5	44.00
X-40	MDC-9	243	1R	95	165	70	23.1	2.98
AiResist 215	None	246	2F	150	165	15	39.9	5.14
AiResist 215	None	245	2R	125	165	40	122.3	15.76
AiResist 215	None	244	2Q	120	165	45	144.3	18.59

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

TABLE 55

WEIGHT OF SURFACE SCALE ON TEST SPECIMENS
(0.040 wt % Sulfur — 0.1 vol % CI-2)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Weight of Surface Scale mg	mg/cm^2
B-1900	None	501	3A	95	100	5	67.4	8.68
B-1900	None	503	3A	115	120	5	97.3	12.54
B-1900	None	505	3C	155	165	10	108.4	13.97
B-1900	None	502	3B	105	120	15	141.5	18.12
B-1900	None	504	3B	135	150	15	125.5	16.17
B-1900	None	500	3D	90	110	20	151.1	19.47
B-1900	MDC-1	577	2D	110	150	40	93.6	12.06
B-1900	MDC-1	576	2C	100	150	50	117.0	15.08
B-1900	MDC-1	575	2B	90	150	60	134.3	17.31
B-1900	MDC-1	574	2A	80	160	80	156.2	20.13
B-1900	MDC-9	612	2A	0	80	80	99.3	12.80
B-1900	MDC-9	613	2B	0	90	90	87.3	11.25
B-1900	MDC-9	614	2C	0	100	100	119.8	15.44
B-1900	MDC-9	615	2D	0	110	110	127.1	16.38
Mar M-246	None	506	3A	100	105	5	130.9	16.87
Mar M-246	None	508	3A	120	125	5	128.5	16.56
Mar M-246	None	510	3D	150	160	10	156.9	20.22
Mar M-246	None	509	3B	120	135	15	221.9	28.59
Mar M-246	None	511	3B	150	165	15	194.5	25.06
Mar M-246	None	507	3D	110	130	20	331.6	42.73
Mar M-246	MDC-1	581	2H	110	150	40	116.6	15.02
Mar M-246	MDC-1	580	2G	100	150	50	133.8	17.24
Mar M-246	MDC-1	579	2F	90	150	60	141.3	18.21
Mar M-246	MDC-1	578	2E	80	160	80	193.7	24.96
Mar M-246	MDC-9	616	2E	0	80	80	83.7	10.79
Mar M-246	MDC-9	617	2F	0	90	90	129.9	16.74
Mar M-246	MDC-9	618	2G	0	100	100	121.9	15.71
Mar M-246	MDC-9	619	2H	0	110	110	138.6	17.86
Mar M-200	None	513	3A	105	110	5	160.4	20.67
Mar M-200	None	514	3A	125	130	5	156.2	20.13
Mar M-200	None	517	3A	155	165	10	277.8	35.80
Mar M-200	None	512	3C	95	110	15	304.4	39.22
Mar M-200	None	515	3C	125	140	15	307.8	39.66
Mar M-200	None	516	3D	130	150	20	360.3	46.43

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

TABLE 55 (Cont'd)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Weight of Surface Scale mg	mg/cm^2
Mar M-200	MDC-1	585	2M	110	150	40	105.7	13.62
Mar M-200	MDC-1	584	2L	100	150	50	126.6	16.31
Mar M-200	MDC-1	583	2K	90	150	60	133.1	17.15
Mar M-200	MDC-1	582	2J	80	160	80	189.4	24.41
Mar M-200	MDC-9	620	2J	0	80	80	110.7	14.26
Mar M-200	MDC-9	621	2K	0	90	90	129.7	16.71
Mar M-200	MDC-9	622	2L	0	100	100	139.6	17.99
Mar M-200	MDC-9	623	2M	0	110	110	121.5	15.66
IN-100	None	519	3A	110	115	5	73.6	9.48
IN-100	None	521	3A	130	135	5	80.6	10.39
IN-100	None	518	3B	95	105	10	132.1	17.02
IN-100	None	520	3C	110	125	15	173.4	22.34
IN-100	None	523	3C	140	155	15	136.2	17.55
IN-100	None	522	3A	135	155	20	191.9	24.73
IN-100	MDC-1	589	2R	80	120	40	143.9	18.54
IN-100	MDC-1	588	2Q	65	115	50	105.5	13.60
IN-100	MDC-1	587	2P	55	115	60	76.7	9.88
IN-100	MDC-1	586	2N	45	125	80	95.6	12.32
IN-100	MDC-9	624	2N	0	45	45	128.1	16.51
IN-100	MDC-9	625	2P	0	55	55	161.0	20.75
IN-100	MDC-9	626	2Q	0	65	65	97.5	12.56
IN-100	MDC-9	627	2R	0	80	80	59.5	7.67
Inconel 713C	None	530	1K	85	95	10	118.7	15.30
Inconel 713C	None	525	1N	50	60	10	92.5	11.92
Inconel 713C	None	527	1K	65	85	20	111.2	14.33
Inconel 713C	None	531	1N	120	140	20	141.2	18.20
Inconel 713C	None	526	1L	50	80	30	163.1	21.02
Inconel 713 C	None	528	1L	80	110	30	174.5	22.49
Inconel 713C	None	524	1M	40	80	40	183.4	23.63
Inconel 713C	None	529	1M	80	120	40	235.4	30.33
Inconel 713C	MDC-1	590	1E	0	35	35	107.9	13.90
Inconel 713C	MDC-1	597	1H	80	120	40	108.1	13.93
Inconel 713C	MDC-1	591	1F	0	50	50	88.0	11.34
Inconel 713C	MDC-1	596	1G	65	115	50	139.7	18.00
Inconel 713C	MDC-1	592	1G	0	65	65	130.2	16.78
Inconel 713C	MDC-1	595	1F	50	115	65	186.5	24.03

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

TABLE 55 (Cont'd)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Weight of Surface Scale mg	mg/cm²
Inconel 713C	MDC-1	593	1H	0	80	80	118.7	15.30
Inconel 713C	MDC-1	594	1E	35	115	80	218.7	28.18
Inconel 713C	MDC-9	628	3J	0	165	165	212.2	27.34
Inconel 713C	MDC-9	629	3K	0	165	165	174.1	22.43
Udimet 700	None	537	1D	130	140	10	112.6	14.51
Udimet 700	None	538	1D	140	150	10	110.5	14.24
Udimet 700	None	536	1L	110	130	20	287.1	37.00
Udimet 700	None	539	1M	140	160	20	159.2	20.51
Udimet 700	None	533	1C	65	95	30	193.2	24.90
Udimet 700	None	535	1C	95	125	30	234.9	30.27
Udimet 700	None	532	1D	50	90	40	153.6	19.79
Udimet 700	None	534	1D	90	130	40	180.4	22.25
Udimet 700	MDC-1	598	1M	0	40	40	155.4	20.02
Udimet 700	MDC-1	599	1L	0	50	50	152.5	19.65
Udimet 700	MDC-1	600	1K	0	65	65	145.5	18.75
Udimet 700	MDC-1	601	1J	0	80	80	193.7	24.96
Udimet 700	MDC-9	633	3L	90	165	75	79.9	10.30
Udimet 700	MDC-9	630	3M	0	75	75	65.3	8.42
Udimet 700	MDC-9	631	3L	0	90	90	173.2	22.32
Udimet 700	MDC-9	632	3M	75	165	90	101.9	13.13
IN-738	None	541	1E	115	125	10	205.4	26.47
IN-738	None	542	1M	120	140	20	357.8	46.11
IN-738	None	544	1L	130	160	30	525.6	67.73
IN-738	None	543	1Q	120	160	40	507.2	65.36
IN-738	None	540	1J	80	140	60	868.4	111.90
IN-738	MDC-1	606	1F	115	155	40	124.2	16.00
IN-738	MDC-1	602	1D	0	50	50	105.0	13.53
IN-738	MDC-1	603	1C	0	65	65	132.4	17.06
IN-738	MDC-1	604	1B	0	80	80	126.1	16.25
IN-738	MDC-1	605	1A	0	95	95	156.7	20.19
IN-738	MDC-9	634	3N	0	165	165	201.0	25.90
IN-738	MDC-9	635	3P	0	165	165	379.3	48.88
Udimet 710	None	548	1E	115	125	10	107.3	13.83
Udimet 710	None	550	1J	140	160	20	167.0	21.52

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

TABLE 55 (Cont'd)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Weight of Surface Scale mg	mg/cm²
Udimet 710	None	549	1H	120	150	30	251.3	32.38
Udimet 710	None	547	1Q	80	120	40	720.4	92.83
Udimet 710	None	545	1N	60	120	60	840.6	108.32
Udimet 710	None	546	1P	65	145	80	569.8	73.42
Udimet 710	MDC-1	611	1G	115	155	40	113.0	14.56
Udimet 710	MDC-1	607	1N	0	50	50	157.4	20.28
Udimet 710	MDC-1	608	1P	0	65	65	212.9	27.43
Udimet 710	MDC-1	609	1Q	0	80	80	223.9	28.85
Udimet 710	MDC-1	610	1R	0	95	95	319.9	41.22
Udimet 710	MDC-9	636	3R	0	55	55	85.3	10.99
Udimet 710	MDC-9	639	3Q	90	165	75	84.9	10.94
Udimet 710	MDC-9	637	3Q	0	90	90	194.8	25.10
Udimet 710	MDC-9	638	3R	55	165	110	104.9	13.52
WI-52	None	554	2N	125	145	20	200.6	25.85
WI-52	None	555	3H	140	165	25	197.6	25.46
WI-52	None	553	3G	125	165	40	268.9	34.65
WI-52	None	552	3F	110	165	55	327.4	42.19
WI-52	None	551	3E	95	165	70	387.9	49.98
WI-52	MDC-9	640	1A	95	165	70	193.9	24.99
Mar M-509	None	563	3D	70	90	20	236.3	30.45
Mar M-509	None	556	3A	0	25	25	202.7	26.12
Mar M-509	None	557	3B	0	40	40	169.7	21.88
Mar M-509	None	562	3C	55	95	40	222.0	26.61
Mar M-509	None	558	3C	0	55	55	214.3	27.62
Mar M-509	None	561	3B	40	95	55	287.1	37.00
Mar M-509	None	559	3D	0	70	70	214.1	27.59
Mar M-509	None	560	3A	25	95	70	331.6	42.73
Mar M-509	MDC-9	641	1B	80	150	70	197.8	25.49
Mar M-302	None	568	2P	115	135	20	252.6	32.55
Mar M-302	None	567	3H	115	140	25	279.5	36.02
Mar M-302	None	566	3G	85	125	40	315.2	40.62
Mar M-302	None	565	3F	55	110	55	348.9	44.96
Mar M-302	None	564	3E	25	95	70	406.3	52.36
Mar M-302	MDC-9	642	1K	95	165	70	187.1	24.11

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row. Letter = Position in Row.

TABLE 55 (Cont'd)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Weight of Surface Scale mg	Weight of Surface Scale mg/cm²
X-40	None	573	2P	135	155	20	173.5	22.36
X-40	None	569	3E	0	25	25	152.7	19.68
X-40	None	570	3F	0	55	55	229.9	29.63
X-40	None	571	3G	0	85	85	383.4	49.40
X-40	None	572	3H	0	115	115	721.1	92.92
X-40	MDC-9	643	1R	95	165	70	190.7	24.57
AiResist 215	None	646	2F	150	165	15	118.7	15.30
AiResist 215	None	645	2R	120	160	40	200.1	25.78
AiResist 215	None	644	2Q	115	160	45	220.8	28.45

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

TABLE 56

WEIGHT LOSS DATA FOR TEST SPECIMENS
(0.040 Weight Per Cent Sulfur in Fuel)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Specimen Weight Loss mg	mg/cm2
B-1900	None	14	1C	145	150	5	47.3	6.10
B-1900	None	11	1Q	120	125	5	32.4	4.18
B-1900	None	5	2A	80	85	5	75.9	9.78
B-1900	None	3	2N	45	50	5	119.4	15.39
B-1900	None	7	3A	95	100	5	26.7	3.44
B-1900	None	10	3A	115	120	5	15.2	1.96
B-1900	None	16	3C	155	165	10	163.3	21.04
B-1900	None	4	1D	50	65	15	798.9	102.95
B-1900	None	9	1E	115	130	15	724.2	93.32
B-1900	None	15	2G	150	165	15	572.4	73.56
B-1900	None	12	2N	130	145	15	738.7	95.19
B-1900	None	8	3B	105	120	15	529.1	68.18
B-1900	None	13	3B	135	150	15	405.9	52.30
B-1900	None	6	3D	90	110	20	1029.3	132.64
B-1900	MDC-1	131	2D	125	165	40	534.0	68.81*
B-1900	MDC-1	130	2C	115	165	50	108.9	14.03*
B-1900	MDC-1	129	2B	105	165	60	269.0	34.66*
B-1900	None	128	2A	85	165	80	611.4	78.78
B-1900	MDC-9	180	2A	0	80	80	41.9	5.40
B-1900	MDC-9	181	2B	0	90	90	39.1	5.04
B-1900	MDC-9	182	2C	0	100	100	33.2	4.28
B-1900	MDC-9	183	2D	0	110	110	51.7	6.66*
Mar M-246	None	23	1L	110	115	5	277.4	35.75
Mar M-246	None	27	1P	145	150	5	240.6	31.00
Mar M-246	None	32	2E	160	165	5	177.7	22.90
Mar M-246	None	19	2P	55	60	5	188.1	24.24
Mar M-246	None	22	3A	100	105	5	290.8	37.47
Mar M-246	None	25	3A	120	125	5	104.7	13.49
Mar M-246	None	31	3D	150	160	10	335.2	43.19
Mar M-246	None	20	1C	65	80	15	964.8	124.32
Mar M-246	None	28	1H	150	165	15	1158.9	149.34
Mar M-246	None	21	2B	90	105	15	1200.2	154.66
Mar M-246	None	29	2K	150	165	15	980.0	126.28
Mar M-246	None	26	3B	120	135	15	649.5	83.70
Mar M-246	None	30	3B	150	165	15	627.2	80.82
Mar M-246	None	24	3D	110	130	20	1114.7	143.64

* Localized attack.

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

TABLE 56 (Cont'd)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Specimen Weight Loss mg	mg/cm²
Mar M-246	MDC-1	137	2H	110	150	40	571.2	73.60*
Mar M-246	MDC-1	136	2G	100	150	50	66.1	8.52*
Mar M-246	MDC-1	135	2F	90	150	60	168.4	21.70*
Mar M-246	NDC-1	134	2E	80	160	80	591.4	76.21*
Mar M-246	MDC-9	186	2E	0	80	80	37.0	4.77
Mar M-246	MDC-9	187	2F	0	90	90	34.0	4.38
Mar M-246	MDC-9	188	2G	0	100	100	32.1	4.14
Mar M-246	MDC-9	189	2H	0	110	110	48.5	6.25*
Mar H-200	None	40	1M	120	125	5	173.4	22.34
Mar M-200	None	35	2Q	65	70	5	291.3	37.54
Mar M-200	None	39	3A	105	110	5	245.5	31.64
Mar M-200	None	41	3A	125	130	5	229.8	29.61
Mar M-200	None	46	3A	155	165	10	341.8	44.04
Mar M-200	None	36	1B	80	95	15	1170.3	150.80
Mar M-200	None	44	1P	150	165	15	1189.4	153.27
Mar M-200	None	38	2C	100	115	15	1172.7	151.11
Mar M-200	None	45	2L	150	165	15	908.6	117.08
Mar M-200	None	37	3C	95	110	15	1029.6	132.67
Mar M-200	None	42	3C	125	140	15	858.1	110.57
Mar M-200	None	43	3D	130	150	20	1104.9	142.38
Mar M-200	MDC-1	143	2M	110	150	40	271.3	34.96
Mar M-200	MDC-1	142	2L	100	150	50	609.1	78.49
Mar M-200	MDC-1	141	2K	90	150	60	1019.4	131.36
Mar M-200	MDC-1	140	2J	80	160	80	1606.1	206.96
Mar M-200	MDC-9	192	2J	0	80	80	322.0	41.49*
Mar M-200	MDC-9	193	2K	0	90	90	54.1	6.97*
Mar M-200	MDC-9	194	2L	0	100	100	100.0	12.89*
Mar M-200	MDC-9	195	2M	0	110	110	211.1	27.20*
IN-100	None	56	1C	140	145	5	167.5	21.58
IN-100	None	62	1J	160	165	5	124.8	16.08
IN-100	None	60	2H	150	155	5	79.6	10.26
IN-100	None	49	2R	80	85	5	174.9	22.54
IN-100	None	52	3A	110	115	5	231.2	29.79
IN-100	None	54	3A	130	135	5	53.2	6.86
IN-100	None	50	3B	95	105	10	351.8	45.33

* Localized Attack.

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

TABLE 56 (Cont'd)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Specimen Weight Loss mg	mg/cm²
IN-100	None	59	1C	150	165	15	888.6	114.50
IN-100	None	57	1N	140	155	15	916.3	118.07
IN-100	None	51	2D	110	125	15	793.9	102.30
IN-100	None	61	2M	150	165	15	406.5	52.38
IN-100	None	53	3C	110	125	15	727.8	93.78
IN-100	None	58	3C	140	155	15	567.8	73.17
IN-100	None	55	3A	135	155	20	1016.1	130.94
IN-100	MDC-1	149	2R	85	125	40	514.5	66.30
IN-100	MDC-1	148	2Q	70	120	50	1373.0	176.92
IN-100	MDC-1	147	2P	60	120	60	1818.2	234.29
IN-100	MDC-1	146	2N	50	130	80	2767.0	356.56
IN-100	MDC-9	198	2N	0	45	45	23.5	3.03
IN-100	MDC-9	199	2P	0	55	55	262.4	33.81*
IN-100	MDC-9	200	2Q	0	65	65	1582.8	203.96
IN-100	MDC-9	201	2R	0	80	80	1329.4	171.31
Inconel 713C	None	71	1K	85	95	10	203.5	26.22
Inconel 713C	None	67	1N	50	60	10	216.7	27.92
Inconel 713C	None	68	1K	65	85	20	530.7	68.39
Inconel 713C	None	72	1N	120	140	20	576.2	74.25
Inconel 713C	None	66	1L	50	80	30	1015.1	130.81
Inconel 713C	None	69	1L	80	110	30	1281.3	165.11
Inconel 713C	None	65	1M	40	80	40	1398.1	180.16
Inconel 713C	None	70	1M	80	120	40	1704.8	219.68
Inconel 713C	MDC-1	152	1E	0	35	35	55.5	7.15
Inconel 713C	MDC-1	159	1H	80	120	40	28.3	3.65
Inconel 713C	MDC-1	153	1F	0	50	50	390.1	50.27
Inconel 713C	MDC-1	158	1G	65	115	50	178.8	23.04
Inconel 713C	MDC-1	154	1G	0	65	65	1137.1	146.53
Inconel 713C	MDC-1	157	1F	50	115	65	272.9	35.17
Inconel 713C	MDC-1	155	1H	0	80	80	1519.5	195.80
Inconel 713C	MDC-1	156	1E	35	115	80	518.1	66.76
Inconel 713C	MDC-9	204	3J	0	165	165	2113.6	272.36
Inconel 713C	MDC-9	205	3K	0	165	165	1834.0	236.33
Udimet 700	None	80	1D	145	155	10	39.8	5.13
Udimet 700	None	82	1D	155	165	10	33.4	4.30
Udimet 700	None	79	1L	115	135	20	285.9	36.84
Udimet 700	None	81	1M	145	165	20	228.5	29.44

* Localized attack.
(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row. Letter = Position in Row.

TABLE 56 (Cont'd)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Specimen Weight Loss mg	mg/cm²
Udimet 700	None	76	1C	80	110	30	849.5	109.47
Udimet 700	None	78	1C	110	140	30	667.9	86.07
Udimet 700	None	75	1D	65	105	40	1081.6	139.38
Udimet 700	None	77	1D	105	145	40	1131.8	145.84
Udimet 700	MDC-1	165	1M	0	40	40	119.7	15.42
Udimet 700	MDC-1	164	1L	0	50	50	258.5	33.31
Udimet 700	MDC-1	163	1K	0	65	65	760.3	97.97
Udimet 700	MDC-1	162	1J	0	80	80	1002.5	129.18
Udimet 700	MDC-9	230	3L	90	165	75	367.7	47.38
Udimet 700	MDC-9	209	3M	0	75	75	63.3	8.16
Udimet 700	MDC-9	208	3L	0	90	90	185.3	23.88
Udimet 700	MDC-9	231	3M	75	165	90	548.5	70.68
IN-738	None	88	1E	130	140	10	45.6	5.88
IN-738	None	86	1M	125	145	20	100.6	12.96
IN-738	None	89	1L	135	165	30	241.7	31.14
IN-738	None	87	1Q	125	165	40	439.8	56.67
IN-738	None	85	1J	80	140	60	1214.4	156.49
IN-738	MDC-1	237	1F	115	155	40	32.7	4.21
IN-738	MDC-1	171	1D	0	50	50	67.9	8.75
IN-738	MDC-1	170	1C	0	65	65	104.1	13.41
IN-738	MDC-1	169	1B	0	80	80	370.2	47.70
IN-738	MDC-1	168	1A	0	95	95	447.4	57.65
IN-738	MDC-9	212	3N	0	165	165	641.5	82.66
IN-738	MDC-9	213	3P	0	165	165	1180.9	152.17
Udimet 710	None	96	1E	140	150	10	42.0	5.41
Udimet 710	None	97	1J	140	160	20	110.8	14.28
Udimet 710	None	95	1H	120	150	30	152.6	19.66
Udimet 710	None	94	1Q	80	120	40	507.6	65.41
Udimet 710	None	92	1N	60	120	60	845.4	108.94
Udimet 710	None	93	1P	65	145	80	1479.1	190.60
Udimet 710	MDC-1	238	1G	115	155	40	69.7	8.98
Udimet 710	MDC-1	174	1N	0	50	50	77.0	9.92
Udimet 710	MDC-1	175	1P	0	65	65	229.3	29.55
Udimet 710	MDC-1	176	1Q	0	80	80	570.8	73.55
Udimet 710	MDC-1	177	1R	0	95	95	743.4	95.79

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

TABLE 56 (Cont'd)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Specimen Weight Loss mg	mg/cm²
Udimet 710	MDC-9	217	3R	0	55	55	47.5	6.12
Udimet 710	MDC-9	227	3Q	90	165	75	66.6	8.58
Udimet 710	MDC-9	216	3Q	0	90	90	439.6	56.65
Udimet 710	MDC-9	226	3R	55	165	110	277.7	35.78
WI-52	None	234	2N	145	165	20	210.6	27.14
WI-52	None	103	3H	140	165	25	367.6	47.37
WI-52	None	102	3G	125	165	40	691.2	89.07
WI-52	None	101	3F	110	165	55	801.8	103.32
WI-52	None	100	3E	95	165	70	974.1	125.52
WI-52	MDC-9	240	1A	95	165	70	16.7	2.15
Mar M-509	None	113	3D	70	90	20	72.5	9.34
Mar M-509	None	106	3A	0	25	25	160.6	20.70
Mar M-509	None	107	3B	0	40	40	178.1	22.95
Mar M-509	None	112	3C	55	95	40	169.0	21.78
Mar M-509	None	108	3C	0	55	55	247.5	31.89
Mar M-509	None	111	3B	40	95	55	262.7	33.85
Mar M-509	None	109	3D	0	70	70	296.1	38.16
Mar M-509	None	110	3A	25	95	70	414.0	53.35
Mar M-509	MDC-9	241	1B	95	165	70	56.0	7.22
Mar M-302	None	235	2P	120	140	20	94.1	12.13
Mar M-302	None	119	3H	115	140	25	164.4	21.18
Mar M-302	None	118	3G	85	125	40	270.3	34.83
Mar M-302	None	117	3F	55	110	55	322.2	41.52
Mar M-302	None	116	3E	25	95	70	417.8	53.84
Mar M-302	MDC-9	242	1K	95	165	70	390.5	50.32*
X-40	None	236	2P	140	160	20	95.1	12.25
X-40	None	122	3E	0	25	25	89.2	11.49
X-40	None	123	3F	0	55	55	213.6	27.52
X-40	None	124	3G	0	85	85	414.4	53.40
X-40	None	125	3H	0	115	115	693.5	89.36
X-40	MDC-9	243	1R	95	165	70	16.3	2.10
AiResist 215	None	246	2P	150	165	15	36.1	4.65
AiResist 215	None	245	2R	125	165	40	109.7	14.14
AiResist 215	None	244	2Q	120	165	45	131.1	16.89

* Localized Attack.
(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row. Letter = Position in Row.

TABLE 57

WEIGHT LOSS DATA FOR TEST SPECIMENS
(0.040 wt % Sulfur - 0.1 vol % CI-2)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Specimen weight loss mg	mg/cm²
B-1900	None	501	3A	95	100	5	69.8	8.99
B-1900	None	503	3A	115	120	5	67.8	8.74
B-1900	None	505	3C	155	165	10	284.6	36.67
B-1900	None	502	3B	105	120	15	717.8	92.50
B-1900	None	504	3B	135	150	15	814.9	105.01
B-1900	None	500	3D	90	110	20	1278.5	164.75
B-1900	MDC-1	577	2D	110	150	40	30.5	3.93
B-1900	MDC-1	576	2C	100	150	50	33.6	4.33
B-1900	MDC-1	575	2B	90	150	60	42.0	5.41
B-1900	MDC-1	574	2A	80	160	80	57.7	7.44
B-1900	MDC-9	612	2A	0	80	80	32.0	4.12
B-1900	MDC-9	613	2B	0	90	90	25.6	3.30
B-1900	MDC-9	614	2C	0	100	100	46.5	5.99
B-1900	MDC-9	615	2D	0	110	110	35.2	4.54
Mar M-246	None	506	3A	100	105	5	261.0	33.63
Mar M-246	None	508	3A	120	125	5	316.4	40.77
Mar M-246	None	510	3D	150	160	10	768.9	99.08
Mar M-246	None	509	3B	120	135	15	1150.3	148.23
Mar M-246	None	511	3B	150	165	15	1120.0	144.32
Mar M-246	None	507	3D	110	130	20	1547.2	199.37
Mar M-246	MDC-1	581	2H	110	150	40	39.0	5.03
Mar M-246	MDC-1	580	2G	100	150	50	40.5	5.22
Mar M-246	MDC-1	579	2F	90	150	60	39.3	5.06
Mar M-246	MDC-1	578	2E	80	160	80	65.5	8.44
Mar M-246	MDC-9	616	2E	0	80	80	33.9	4.37
Mar M-246	MDC-9	617	2F	0	90	90	33.8	4.36
Mar M-246	MDC-9	618	2G	0	100	100	40.9	5.27
Mar M-246	MDC-9	619	2H	0	110	110	45.8	5.90*
Mar M-200	None	513	3A	105	110	5	414.6	53.42
Mar M-200	None	514	3A	125	130	5	425.5	54.83
Mar M-200	None	517	3A	155	165	10	674.7	86.94
Mar M-200	None	512	3C	95	110	15	1021.1	131.58
Mar M-200	None	515	3C	125	140	15	1045.1	134.67
Mar M-200	None	516	3D	130	150	20	1564.5	201.60

* Localized Attack.
(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

TABLE 57 (Cont'd)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Specimen weight loss mg	mg/cm²
Mar M-200	MDC-1	585	2M	110	150	40	30.2	3.89
Mar M-200	MDC-1	584	2L	100	150	50	33.4	4.30
Mar M-200	MDC-1	583	2K	90	150	60	37.8	4.87
Mar M-200	MDC-1	582	2J	80	160	80	88.5	11.40
Mar M-200	MDC-9	620	2J	0	80	80	291.2	37.52*
Mar M-200	MDC-9	621	2K	0	90	90	97.1	12.51*
Mar M-200	MDC-9	622	2L	0	100	100	132.9	17.12*
Mar M-200	MDC-9	623	2M	0	110	110	438.5	56.50*
IN-100	None	519	3A	110	115	5	224.0	28.86
IN-100	None	521	3A	130	135	5	180.5	23.26
IN-100	None	518	3B	95	105	10	402.4	51.85
IN-100	None	520	3C	110	125	15	973.5	125.44
IN-100	None	523	3C	140	155	15	1004.9	129.49
IN-100	None	522	3A	135	155	20	1416.3	182.50
IN-100	MDC-1	589	2R	80	120	40	120.0	15.46*
IN-100	MDC-1	588	2Q	65	115	50	602.9	77.69
IN-100	MDC-1	587	2P	55	115	60	1847.2	238.03
IN-100	MDC-1	586	2N	45	125	80	3362.4	433.28
IN-100	MDC-9	624	2N	0	45	45	77.2	9.95*
IN-100	MDC-9	625	2P	0	55	55	18.5	2.38
IN-100	MDC-9	626	2Q	0	65	65	22.1	2.85
IN-100	MDC-9	627	2R	0	80	80	994.7	128.18
Inconel 713C	None	530	1K	85	95	10	277.4	35.75
Inconel 713C	None	525	1N	50	60	10	367.7	47.38
Inconel 713C	None	527	1K	65	85	20	896.2	115.48
Inconel 713C	None	531	1N	120	140	20	977.8	126.00
Inconel 713C	None	526	1L	50	80	30	1335.5	172.09
Inconel 713C	None	528	1L	80	110	30	1246.7	160.65
Inconel 713C	None	524	1M	40	80	40	2002.1	257.99
Inconel 713C	None	529	1M	80	120	40	1645.6	212.05
Inconel 713C	MDC-1	590	1E	0	35	35	27.4	3.53
Inconel 713C	MDC-1	597	1H	80	120	40	32.5	4.19
Inconel 713C	MDC-1	591	1F	0	50	50	49.7	6.40
Inconel 713C	MDC-1	596	1G	65	115	50	34.4	4.43
Inconel 713C	MDC-1	592	1G	0	65	65	59.8	7.71
Inconel 713C	MDC-1	595	1F	50	115	65	269.8	34.77*

* Localized Attack.

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

TABLE 57 (Cont'd)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Specimen weight loss mg	mg/cm²
Inconel 713C	MDC-1	593	1H	0	80	80	115.5	14.88
Inconel 713C	MDC-1	594	1E	35	115	80	75.0	9.66
Inconel 713C	MDC-9	628	2J	0	165	165	94.6	12.19*
Inconel 713C	MDC-9	629	3K	0	165	165	67.8	8.74
Udimet 700	None	537	1D	130	140	10	81.2	10.46
Udimet 700	None	538	1D	140	150	10	104.7	13.49
Udimet 700	None	536	1L	110	130	20	761.2	98.09
Udimet 700	None	539	1M	140	160	20	591.8	76.26
Udimet 700	None	533	1C	65	95	30	987.3	127.22
Udimet 700	None	535	1C	95	125	30	1318.3	169.88
Udimet 700	None	532	1D	50	90	40	1605.9	206.94
Udimet 700	None	534	1D	90	130	40	1653.2	213.03
Udimet 700	MDC-1	598	1M	0	40	40	31.2	4.02
Udimet 700	MDC-1	599	1L	0	50	50	47.9	6.17
Udimet 700	MDC-1	600	1K	0	65	65	64.1	8.26
Udimet 700	MDC-1	601	1J	0	80	80	191.8	24.72
Udimet 700	MDC-9	633	3L	90	165	75	97.9	12.62*
Udimet 700	MDC-9	630	3M	0	75	75	83.9	10.81
Udimet 700	MDC-9	631	3L	0	90	90	439.3	56.61
Udimet 700	MDC-9	632	3M	75	165	90	59.8	7.71
IN-738	None	541	1E	115	125	10	165.3	21.30
IN-738	None	542	1M	120	140	20	472.2	60.85
IN-738	None	544	1L	130	160	30	775.7	99.96
IN-738	None	543	1Q	120	160	40	1297.1	167.14
IN-738	None	540	1J	80	140	60	2584.6	333.05
IN-738	MDC-1	606	1F	115	155	40	34.0	4.38
IN-738	MDC-1	602	1D	0	50	50	31.7	4.08
IN-738	MDC-1	603	1C	0	65	65	29.7	3.83
IN-738	MDC-1	604	1B	0	80	80	43.5	5.60
IN-738	MDC-1	605	1A	0	95	95	65.6	8.45
IN-738	MDC-9	634	3N	0	165	165	131.8	16.98*
IN-738	MDC-9	635	3P	0	165	165	1348.7	173.79
Udimet 710	None	548	1E	125	135	10	64.3	8.29
Udimet 710	None	550	1J	140	160	20	98.5	12.69

* Localized attack.
(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

TABLE 57 (Cont'd)

Superalloy	Coating	[illegible]c. No.	([illegible]) [illegible]tion	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Specimen weight loss mg	Specimen weight loss mg/cm²
Udimet 710	None	549	1H	120	150	30	20[illegible].6	26.24
Udimet 710	None	547	1Q	80	120	40	883.3	113.82
Udimet 710	None	545	1N	60	120	60	1767.5	227.76
Udimet 710	None	546	1P	65	145	80	3167.2	408.12
Udimet 710	MDC-1	611	1G	115	155	40	39.6	5.10
Udimet 710	MDC-1	607	1N	0	50	50	56.1	7.23*
Udimet 710	MDC-1	608	1P	0	65	65	101.2	13.04*
Udimet 710	MDC-1	609	1Q	0	80	80	196.5	25.32*
Udimet 710	MDC-1	610	1R	0	95	95	654.0	84.27
Udimet 710	MDC-9	636	3R	0	55	55	30.8	3.97
Udimet 710	MDC-9	639	3Q	90	165	75	53.3	6.87
Udimet 710	MDC-9	637	3Q	0	90	90	248.6	32.03
Udimet 710	MDC-9	638	3R	55	165	110	59.7	7.69
WI-52	None	554	2N	125	145	20	298.5	38.46
WI-52	None	555	3H	140	165	25	350.0	45.10
WI-52	None	553	3G	125	165	40	377.2	48.61
WI-52	None	552	3F	110	165	55	447.4	57.65
WI-52	None	551	3E	95	165	70	536.9	69.18
WI-52	MDC-9	640	1A	95	165	70	153.4	19.77
Mar M-509	None	563	3D	70	90	20	146.8	18.92
Mar M-509	None	556	3A	0	25	25	128.3	16.53
Mar M-509	None	557	3B	0	40	40	203.5	26.22
Mar M-509	None	562	3C	55	95	40	192.6	24.82
Mar M-509	None	558	3C	0	55	55	307.6	39.64
Mar M-509	None	561	3B	40	95	55	299.4	38.58
Mar M-509	None	559	3D	0	70	70	448.5	57.79
Mar M-509	None	560	3A	25	95	70	473.2	60.98
Mar M-509	MDC-9	641	1B	80	150	70	92.7	11.9[illegible]
Mar M-302	None	568	2P	115	135	20	175.5	22.62
Mar M-302	None	567	3H	115	140	25	189.7	24.44
Mar M-302	None	566	3G	85	125	40	182.9	23.57
Mar M-302	None	565	3F	55	110	55	351.0	45.23
Mar M-302	None	564	3E	25	95	70	599.3	77.23
Mar M-302	MDC-9	642	1K	95	165	70	119.0	15.33

* Localized attack.

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

TABLE 57 (Cont'd)

Superalloy	Coating	Spec. No.	(a) Position	Spec. In, hrs.	Spec. Out, hrs.	Exposure Time, hrs.	Specimen weight loss mg	mg/cm2
X-40	None	573	2P	135	155	20	130.3	16.79
X-40	None	569	3E	0	25	25	119.8	15.44
X-40	None	570	3F	0	55	55	325.4	41.93
X-40	None	571	3G	0	85	85	625.8	80.64
X-40	None	572	3H	0	115	115	1416.8	182.57
X-40	MDC-9	643	1R	95	165	70	83.2	10.72
AiResist 215	None	646	2F	150	165	15	65.0	8.38
AiResist 215	None	645	2R	120	160	40	113.7	14.65
AiResist 215	None	644	2Q	115	160	45	126.0	16.24

(a) Position in holder: 1 = Front Row, 2 = Second Row, 3 = Rear Row.
Letter = Position in Row.

TABLE 58

PENETRATION DATA FOR SURFACE LOSS[a] FOR SPECIMENS FROM BASE-LINE[b] TEST

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Surface Loss, mils				
				At Location of Average Visual Attack		At Location of Maximum Visual Attack		Mean
B-1900	None	7	5	2.5	-7.5	7.0	1.0	0.8
B-1900	None	10	5	-3.2	-3.2	3.8	3.8	0.3
B-1900	None	16	10	2.0	-1.0	0.0	2.0	0.8
B-1900	None	8	15	10.8	14.3	10.8	15.8	12.9
B-1900	None	13	15	12.1	0.6	14.1	-3.4	5.9
B-1900	None	6	20	23.3	23.3	23.8	21.3	22.9
B-1900	MDC-1	131	40	2.0	0.0	55.5	16.5	18.5 *
B-1900	MDC-1	130	50	2.4	0.9	7.9	2.4	3.4 *
B-1900	MDC-1	129	60	0.6	3.6	19.6	15.6	9.9 *
B-1900	MDC-1	128	80	16.0	18.5	21.0	20.5	19.0
B-1900	MDC-9	180	80	2.5	3.0	4.5	0.0	2.5
B-1900	MDC-9	181	90	3.6	1.1	16.1	7.1	7.0
B-1900	MDC-9	182	100	3.1	0.6	12.6	2.6	4.7
B-1900	MDC-9	183	110	2.1	5.1	5.1	6.1	4.6 *
Mar M-246	None	22	5	9.5	11.5	13.0	9.0	10.8
Mar M-246	None	25	5	3.9	8.4	9.9	3.9	6.5
Mar M-246	None	31	10	12.0	9.0	13.0	3.0	9.2
Mar M-246	None	26	15	14.5	11.0	22.0	7.0	13.6
Mar M-246	None	30	15	7.6	12.6	19.6	11.6	12.8
Mar M-246	None	24	20	5.5	26.0	26.5	19.0	19.2
Mar M-246	MDC-1	137	40	-4.0	3.5	3.0	25.0	6.9 *
Mar M-246	MDC-1	136	50	3.4	-0.1	4.9	4.9	3.3 *
Mar M-246	MDC-1	135	60	4.0	-5.0	18.0	5.0	5.5 *
Mar M-246	MDC-1	134	80	0.5	11.5	9.5	19.5	10.2 *
Mar M-246	MDC-9	186	80	4.5	3.5	5.5	3.5	4.2
Mar M-246	MDC-9	187	90	4.3	3.3	4.3	5.8	4.4
Mar M-246	MDC-9	188	100	3.8	5.3	10.8	6.3	6.6
Mar M-246	MDC-9	189	110	0.7	5.7	2.7	5.7	3.7 *
Mar M-200	None	39	5	4.9	5.4	3.4	9.4	5.8
Mar M-200	None	41	5	7.1	7.1	7.6	6.1	7.0
Mar M-200	None	46	10	9.5	10.0	23.5	7.0	12.5
Mar M-200	None	37	15	21.4	22.4	24.9	18.4	21.8
Mar M-200	None	42	15	17.6	16.1	16.1	24.6	18.6
Mar M-200	None	43	20	25.1	6.6	32.6	19.6	21.0

TABLE 58 (Cont'd)

Superalloy	Coating	Spec. No.	Exposure Time, hrs.	Surface Loss, mils: At Location of Average Visual Attack		Surface Loss, mils: At Location of Maximum Visual Attack		Mean
Mar M-200	MDC-1	143	40	5.6	2.6	17.6	10.1	9.0
Mar M-200	MDC-1	142	50	1.9	1.9	25.9	24.9	13.6
Mar M-200	MDC-1	141	60	23.4	14.9	24.9	36.4	24.9
Mar M-200	MDC-1	140	80	47.8	50.3	57.8	35.8	47.9
Mar M-200	MDC-9	192	80	4.5	4.5	7.5	5.5	5.5 *
Mar M-200	MDC-9	193	90	4.1	3.6	5.1	3.1	4.0 *
Mar M-200	MDC-9	194	100	5.1	5.1	6.1	3.1	4.8 *
Mar M-200	MDC-9	195	110	-2.5	7.5	1.0	11.5	4.4 *
IN-100	None	52	5	0.9	4.4	10.4	6.4	5.5
IN-100	None	54	5	3.5	3.0	4.0	3.0	3.4
IN-100	None	50	10	4.0	10.5	10.5	8.5	8.4
IN-100	None	53	15	4.9	20.9	23.4	19.4	17.2
IN-100	None	58	15	17.1	16.6	3.1	19.6	14.1
IN-100	None	55	20	9.9	21.4	6.9	33.9	18.0
IN-100	MDC-1	149	40	-0.4	13.6	15.6	22.6	12.8
IN-100	MDC-1	148	50	7.4	5.9	41.4	54.9	27.4
IN-100	MDC-1	147	60	36.4	31.9	62.9	67.4	49.6
IN-100	MDC-1	146	80	48.8	46.8	85.3	97.3	69.6
IN-100	MDC-9	198	45	4.1	2.6	6.1	3.6	4.1
IN-100	MDC-9	199	55	4.3	4.3	18.3	5.3	8.0 *
IN-100	MDC-9	200	65	12.6	13.1	21.6	51.6	24.7
IN-100	MDC-9	201	80	10.1	3.1	70.1	73.6	39.2
Inconel 713C	None	71	10	5.6	3.6	5.1	6.6	5.2
Inconel 713C	None	67	10	8.9	7.9	9.4	6.9	8.3
Inconel 713C	None	68	20	11.6	17.6	8.1	18.6	13.9
Inconel 713C	None	72	20	9.1	7.6	15.6	6.6	9.7
Inconel 713C	None	66	30	23.9	22.9	18.9	24.9	22.6
Inconel 713C	None	69	30	21.4	30.9	34.4	28.4	28.8
Inconel 713C	None	65	40	25.0	28.0	27.0	41.5	30.4
Inconel 713C	None	70	40	27.0	33.0	32.5	43.0	33.9
Inconel 713C	MDC-1	152	35	6.8	1.8	7.8	5.3	5.4
Inconel 713C	MDC-1	159	40	2.5	4.0	2.0	6.0	3.6
Inconel 713C	MDC-1	153	50	6.6	8.1	17.1	29.6	15.4
Inconel 713C	MDC-1	158	50	-0.6	6.4	12.4	10.4	7.2
Inconel 713C	MDC-1	154	65	5.0	3.0	45.5	34.0	21.9
Inconel 713C	MDC-1	157	65	3.8	7.8	0.8	13.8	6.6
Inconel 713C	MDC-1	155	80	9.3	10.3	43.3	54.8	29.4
Inconel 713C	MDC-1	156	80	10.5	4.5	23.5	24.5	15.8

TABLE 58 (Cont'd)

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Surface Loss, mils: At Location of Average Visual Attack		At Location of Maximum Visual Attack		Mean
Inconel 713C	MDC-9	204	165	52.4	53.4	53.4	66.4	56.4
Inconel 713C	MDC-9	205	165	19.3	14.3	53.8	59.3	36.7
Udimet 700	None	80	10	1.0	3.5	2.5	4.0	2.8
Udimet 700	None	82	10	1.4	-0.6	2.9	3.9	1.9
Udimet 700	None	79	20	7.9	6.4	10.9	11.9	9.3
Udimet 700	None	81	20	2.1	4.6	6.6	8.1	5.4
Udimet 700	None	76	30	12.4	13.4	11.4	17.4	13.6
Udimet 700	None	78	30	17.4	12.4	15.4	17.4	15.6
Udimet 700	None	75	40	23.6	19.1	24.6	24.1	22.8
Udimet 700	None	77	40	22.0	19.0	22.5	26.0	22.4
Udimet 700	MDC-1	165	40	4.8	3.8	9.3	6.8	6.2
Udimet 700	MDC-1	164	50	-1.1	8.9	9.9	1.9	4.9
Udimet 700	MDC-1	163	65	4.5	7.5	23.5	31.0	16.6
Udimet 700	MDC-1	162	80	12.8	13.3	29.3	38.8	23.5
Udimet 700	MDC-9	230	75	10.1	18.6	9.1	19.1	14.2
Udimet 700	MDC-9	209	75	1.1	1.6	5.1	6.6	3.6
Udimet 700	MDC-9	208	90	6.1	4.1	5.1	6.1	5.4
Udimet 700	MDC-9	231	90	2.6	4.6	8.6	16.6	8.1
IN-738	None	88	10	3.5	3.5	4.5	2.5	3.5
IN-738	None	86	20	1.1	1.1	0.1	4.1	1.6
IN-738	None	89	30	5.3	8.3	6.8	9.3	7.4
IN-738	None	87	40	7.4	7.9	10.9	10.4	9.2
IN-738	None	85	60	16.4	20.4	14.4	24.4	18.9
IN-738	MDC-1	237	40	4.3	2.8	5.8	8.3	5.3
IN-738	MDC-1	171	50	4.5	2.5	5.0	4.5	4.1
IN-738	MDC-1	170	65	4.6	4.6	8.6	6.6	6.1
IN-738	MDC-1	169	80	-2.4	7.6	1.6	22.6	7.4
IN-738	MDC-1	168	95	3.9	3.4	10.9	19.9	9.5
IN-738	MDC-9	212	165	4.4	11.4	11.4	26.4	13.4
IN-738	MDC-9	213	165	5.8	7.3	38.8	39.8	22.9
Udimet 710	None	96	10	2.1	2.1	4.1	0.6	2.2
Udimet 710	None	97	20	1.0	3.0	7.5	6.0	4.4
Udimet 710	None	95	30	0.5	0.5	5.0	6.0	3.0
Udimet 710	None	94	40	13.1	16.1	8.6	25.1	15.7
Udimet 710	None	92	60	11.8	-2.2	1.8	13.8	6.3
Udimet 710	None	93	80	17.0	30.0	32.0	31.5	27.6

TABLE 58 (Cont'd)

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Surface Loss, mils: At Location of Average Visual Attack		At Location of Maximum Visual Attack		Mean
Udimet 710	MDC-1	238	40	5.0	2.5	11.0	6.0	6.1
Udimet 710	MDC-1	174	50	1.0	3.5	4.0	4.5	3.2
Udimet 710	MDC-1	175	65	-2.9	5.1	-2.9	17.1	4.1
Udimet 710	MDC-1	176	80	4.6	11.1	15.6	19.6	12.7
Udimet 710	MDC-1	177	95	2.5	4.5	24.0	29.0	15.0
Udimet 710	MDC-9	217	55	2.6	4.1	6.6	5.1	4.6
Udimet 710	MDC-9	227	75	-4.3	1.7	3.2	3.2	1.0
Udimet 710	MDC-9	216	90	4.1	4.1	13.6	20.6	10.6
Udimet 710	MDC-9	226	110	-1.5	3.5	8.5	16.5	6.8
WI-52	None	234	20	7.7	7.7	12.7	3.7	8.0
WI-52	None	103	25	9.3	5.3	17.3	8.8	10.2
WI-52	None	102	40	6.0	2.0	11.0	18.0	9.2
WI-52	None	101	55	4.0	5.0	24.0	27.0	15.0
WI-52	None	100	70	22.3	14.8	16.8	24.3	19.6
WI-52	MDC-9	240	70	5.5	6.5	6.5	6.5	6.2
Mar M-509	None	113	20	-5.0	7.0	8.0	5.0	3.8
Mar M-509	None	106	25	0.3	6.3	2.8	8.3	4.4
Mar M-509	None	107	40	-1.1	1.9	2.9	4.9	2.2
Mar M-509	None	112	40	2.9	3.9	6.9	4.9	4.6
Mar M-509	None	108	55	5.1	7.1	10.1	6.1	7.1
Mar M-509	None	111	55	3.3	5.8	4.8	6.3	5.0
Mar M-509	None	109	70	7.3	6.3	6.3	9.3	7.3
Mar M-509	None	110	70	8.2	4.2	7.2	10.2	7.4
Mar M-509	MDC-9	241	70	5.8	5.8	8.8	7.8	7.0
Mar M-302	None	235	20	1.3	2.3	-0.7	5.3	2.0
Mar M-302	None	119	25	2.5	5.5	8.0	8.5	6.1
Mar M-302	None	118	40	0.5	2.5	6.5	19.5	7.2
Mar M-302	None	117	55	2.8	5.8	9.8	7.8	6.5
Mar M-302	None	116	70	5.6	9.6	1.6	13.6	7.6
Mar M-302	MDC-9	242	70	-9.5	12.5	16.5	-5.5	3.5 *

TABLE 58 (Cont'd)

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Surface Loss, mils At Location of Average Visual Attack		At Location of Maximum Visual Attack		Mean
X-40	None	236	20	1.1	5.1	5.1	5.1	4.1
X-40	None	122	25	6.5	1.5	4.5	6.5	4.8
X-40	None	123	55	12.5	4.5	5.0	12.5	8.6
X-40	None	124	85	1.6	-0.4	4.6	10.6	4.1
X-40	None	125	115	6.9	9.9	14.9	10.9	10.6
X-40	MDC-9	243	70	1.0	5.0	5.0	4.0	3.8
AiResist 215	None	246	15	-0.1	4.9	-2.1	5.9	2.2
AiResist 215	None	245	40	-1.0	4.0	2.0	4.0	2.2
AiResist 215	None	244	45	-0.9	5.1	-0.9	6.1	2.4

Notes:

(a) Loss in diameter due to massive oxides and sulfides.

(b) 1 ppm sea salt in air.
0.040 weight per cent sulfur in fuel.

(*) Localized attack.

TABLE 59

PENETRATION DATA FOR SURFACE LOSS[a] FOR SPECIMENS FROM FUEL-ADDITIVE[b] TEST

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Surface Loss, mils: At Location of Average Visual Attack		At Location of Maximum Visual Attack		Mean
B-1900	None	501	5	3.6	2.1	3.1	4.1	3.2
B-1900	None	503	5	2.0	2.0	4.0	1.5	2.4
B-1900	None	505	10	4.8	8.3	5.3	8.8	6.8
B-1900	None	502	15	15.1	19.6	19.6	19.6	18.5
B-1900	None	504	15	13.4	17.9	18.9	19.4	17.4
B-1900	None	500	20	30.6	25.6	33.6	23.6	28.4
B-1900	MDC-1	577	40	1.6	3.1	5.1	3.6	3.4
B-1900	MDC-1	576	50	1.3	3.3	4.8	3.3	3.2
B-1900	MDC-1	575	60	3.5	1.0	0.5	4.5	2.4
B-1900	MDC-1	574	80	5.0	5.0	3.0	7.0	5.0
B-1900	MDC-9	612	80	4.9	1.4	5.9	1.4	3.4
B-1900	MDC-9	613	90	3.0	4.0	5.0	2.0	3.5
B-1900	MDC-9	614	100	4.0	4.5	9.0	6.5	6.0
B-1900	MDC-9	615	110	5.1	1.1	5.6	3.6	3.8
Mar M-246	None	506	5	6.1	7.6	12.1	6.1	8.0
Mar M-246	None	508	5	6.3	7.3	7.8	9.8	7.8
Mar M-246	None	510	10	16.7	14.7	18.7	15.7	16.4
Mar M-246	None	509	15	14.4	23.4	24.4	24.4	21.6
Mar M-246	None	511	15	28.5	14.0	42.0	18.5	25.8
Mar M-246	None	507	20	25.5	32.5	11.5	39.5	27.2
Mar M-246	MDC-1	581	40	-1.7	1.3	1.3	5.3	1.6
Mar M-246	MDC-1	580	50	1.4	4.4	-0.6	16.4	5.4
Mar M-246	MDC-1	579	60	-0.5	4.5	1.5	7.5	3.2
Mar M-246	MDC-1	578	80	3.8	5.8	-0.2	8.8	4.6
Mar M-246	MDC-9	616	80	1.0	-5.0	0.0	5.0	0.2
Mar M-246	MDC-9	617	90	-0.2	4.8	0.8	9.8	3.8
Mar M-246	MDC-9	618	100	-0.2	3.8	-0.2	4.8	2.0
Mar M-246	MDC-9	619	110	-1.9	4.1	1.1	4.1	1.8 *
Mar M-200	None	513	5	5.9	13.4	2.4	16.4	9.5
Mar M-200	None	514	5	4.1	7.1	5.1	11.1	6.8
Mar M-200	None	517	10	7.5	10.5	6.5	15.5	10.0
Mar M-200	None	512	15	16.2	11.2	13.2	26.2	16.7
Mar M-200	None	515	15	10.9	22.9	3.9	25.9	15.9
Mar M-200	None	516	20	23.9	27.9	24.9	27.9	26.2

TABLE 59 (Cont'd)

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Surface Loss, mils: At Location of Average Visual Attack		At Location of Maximum Visual Attack		Mean
Mar M-200	MDC-1	585	40	0.8	6.8	-0.2	4.8	3.0
Mar M-200	MDC-1	584	50	-5.2	1.3	-3.7	6.3	-0.3
Mar M-200	MDC-1	583	60	1.1	-4.9	-1.9	3.1	-0.6
Mar M-200	MDC-1	582	80	0.2	4.2	3.2	4.2	3.0
Mar M-200	MDC-9	620	80	-2.4	2.6	-0.4	4.6	1.1 *
Mar M-200	MDC-9	621	90	0.9	0.9	0.9	4.9	1.9 *
Mar M-200	MDC-9	622	100	-0.2	-2.2	-1.2	-1.2	-1.2 *
Mar M-200	MDC-9	623	110	-0.8	3.2	-1.8	4.2	1.2 *
IN-100	None	519	5	2.2	6.2	2.2	7.2	4.4
IN-100	None	521	5	1.4	2.4	-0.6	8.4	2.9
IN-100	None	518	10	2.8	13.8	0.8	14.8	8.0
IN-100	None	520	15	21.0	21.0	20.0	23.0	21.2
IN-100	None	523	15	17.6	8.6	15.6	26.6	17.1
IN-100	None	522	20	26.0	26.0	22.0	31.0	26.2
IN-100	MDC-1	589	40	1.0	4.0	1.0	6.0	3.0 *
IN-100	MDC-1	588	50	0.9	5.9	32.9	33.9	18.4
IN-100	MDC-1	587	60	19.8	3.8	60.8	75.8	40.0
IN-100	MDC-1	586	80	35.7	59.7	49.7	62.7	52.0
IN-100	MDC-9	624	45	1.5	5.5	5.5	5.5	4.5 *
IN-100	MDC-9	625	55	1.2	4.2	-1.8	5.2	2.2
IN-100	MDC-9	626	65	-0.3	3.7	0.7	6.7	2.7
IN-100	MDC-9	627	90	10.8	10.8	35.8	29.8	21.8
Inconel 713C	None	530	10	-1.6	10.4	3.4	12.4	6.2
Inconel 713C	None	525	10	10.5	11.5	8.5	29.5	15.0
Inconel 713C	None	527	20	15.0	14.0	16.0	21.0	16.5
Inconel 713C	None	531	20	17.3	18.3	18.3	20.3	18.6
Inconel 713C	None	526	30	28.7	34.7	28.7	37.7	32.4
Inconel 713C	None	528	30	32.7	22.7	27.7	41.7	31.2
Inconel 713C	None	524	40	12.9	15.9	45.9	47.9	30.6
Inconel 713C	None	529	40	4.9	13.9	36.9	47.9	25.9
Inconel 713C	MDC-1	590	35	0.6	3.6	-0.4	5.6	2.4
Inconel 713C	MDC-1	597	40	-1.2	-3.2	0.8	6.8	0.8
Inconel 713C	MDC-1	591	50	3.9	4.9	0.9	5.9	3.9
Inconel 713C	MDC-1	596	50	1.3	7.3	0.3	8.3	4.3
Inconel 713C	MDC-1	592	65	1.1	7.1	3.1	8.1	4.8
Inconel 713C	MDC-1	595	65	1.1	6.1	26.1	8.1	10.4 *
Inconel 713C	MDC-1	593	80	1.6	14.6	14.6	6.6	9.4
Inconel 713C	MDC-1	594	80	3.3	6.3	-0.7	8.3	4.3

TABLE 59 (Cont'd)

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Surface Loss, mils: At Location of Average Visual Attack		At Location of Maximum Visual Attack		Mean	
Inconel 713C	MDC-9	628	165	0.0	7.0	-1.0	15.0	5.2	*
Inconel 713C	MDC-9	629	165	1.7	7.7	-1.3	13.7	5.4	
Udimet 700	None	537	10	-2.7	5.3	-1.7	8.3	2.3	
Udimet 700	None	538	10	1.1	4.1	-1.9	6.1	2.4	
Udimet 700	None	536	20	11.0	13.0	8.0	16.0	12.0	
Udimet 700	None	539	20	10.1	13.1	6.1	14.1	10.8	
Udimet 700	None	533	30	10.5	15.5	19.5	21.5	16.8	
Udimet 700	None	535	30	21.8	24.8	18.8	32.8	24.6	
Udimet 700	None	532	40	23.5	27.5	22.5	28.5	25.5	
Udimet 700	None	534	40	13.7	21.7	10.7	23.7	17.4	
Udimet 700	MDC-1	598	40	-4.6	4.4	-1.6	4.4	0.6	
Udimet 700	MDC-1	599	50	-2.5	4.5	-0.5	6.5	2.0	
Udimet 700	MDC-1	600	65	-2.7	5.3	0.3	6.3	2.3	
Udimet 700	MDC-1	601	80	-1.9	4.1	-0.9	4.1	1.4	
Udimet 700	MDC-9	633	75	1.4	7.4	-0.6	8.4	4.2	*
Udimet 700	MDC-9	630	75	1.4	5.4	1.4	8.4	4.2	
Udimet 700	MDC-9	631	90	-3.7	4.3	8.3	10.3	4.8	
Udimet 700	MDC-9	632	90	-0.2	4.8	-1.2	6.8	2.6	
IN-738	None	541	10	-1.6	6.4	0.4	14.4	4.9	
IN-738	None	542	20	3.0	7.0	1.0	8.0	4.8	
IN-738	None	544	30	12.1	18.1	5.1	21.1	14.1	
IN-738	None	543	40	6.2	16.2	16.2	32.2	17.7	
IN-738	None	540	60	30.6	53.6	52.6	66.6	50.8	
IN-738	MDC-1	606	40	-1.2	5.8	-1.2	11.8	3.8	
IN-738	MDC-1	602	50	2.5	5.5	0.5	6.5	3.8	
IN-738	MDC-1	603	65	-2.3	5.7	1.7	5.7	2.7	
IN-738	MDC-1	604	80	0.4	4.4	-0.6	8.4	3.2	
IN-738	MDC-1	605	95	0.5	5.5	-1.5	12.5	4.2	
IN-738	MDC-9	634	165	-1.1	4.9	0.9	6.9	2.9	*
IN-738	MDC-9	635	165	0.4	3.4	35.4	33.4	18.2	
Udimet 710	None	548	10	-4.5	-0.5	-3.5	9.5	0.2	
Udimet 710	None	550	20	-2.2	4.8	0.8	5.8	2.3	
Udimet 710	None	549	30	-3.3	4.7	-2.3	6.7	1.4	
Udimet 710	None	547	40	5.6	30.6	57.6	31.6	31.4	
Udimet 710	None	545	60	31.8	35.8	27.8	36.8	33.0	
Udimet 710	None	546	80	44.1	49.1	67.1	91.1	62.8	

TABLE 59 (Cont'd)

Superalloy	Coat-ing	Spec. No.	Expo-sure Time, hrs	Surface Loss, mils: At Location of Average Visual Attack		At Location of Maximum Visual Attack		Mean
Udimet 710	MDC-1	611	40	-2.9	6.1	-0.9	17.1	4.8
Udimet 710	MDC-1	607	50	-2.6	3.4	-0.6	3.4	0.9 *
Udimet 710	MDC-1	608	65	-0.9	4.1	-0.9	6.1	2.1 *
Udimet 710	MDC-1	609	80	-3.9	4.1	-0.9	6.1	1.4 *
Udimet 710	MDC-1	610	95	-0.7	8.3	7.3	12.3	6.8
Udimet 710	MDC-9	636	55	1.2	6.2	0.2	7.2	3.7
Udimet 710	MDC-9	639	75	0.1	6.1	3.1	7.1	4.1
Udimet 710	MDC-9	637	90	2.9	9.9	2.9	11.9	6.9
Udimet 710	MDC-9	638	110	0.4	4.4	1.4	8.4	3.6
WI-52	None	554	20	-6.8	3.2	11.1	10.2	4.4
WI-52	None	555	25	12.6	7.6	12.6	17.6	12.6
WI-52	None	553	40	11.0	4.0	14.0	8.0	9.2
WI-52	None	552	55	5.0	6.0	9.0	3.0	5.8
WI-52	None	551	70	7.3	9.3	3.3	14.3	8.6
WI-52	MDC-9	640	70	4.7	7.7	9.7	13.7	9.0
Mar M-509	None	563	20	-0.4	2.6	5.6	8.6	4.1
Mar M-509	None	556	25	-3.9	4.1	3.1	6.1	2.4
Mar M-509	None	557	40	4.6	1.6	1.6	13.6	5.4
Mar M-509	None	562	40	7.0	6.0	8.0	13.0	8.5
Mar M-509	None	558	55	7.0	8.0	6.0	13.0	8.5
Mar M-509	None	561	55	2.8	0.8	5.8	5.8	3.8
Mar M-509	None	559	70	5.0	0.0	9.0	8.0	5.5
Mar M-509	None	560	70	6.5	8.5	4.5	15.5	8.8
Mar M-509	MDC-9	641	70	4.6	3.6	4.6	5.6	4.6
Mar M-302	None	568	20	2.3	3.3	3.3	3.3	3.0
Mar M-302	None	567	25	4.4	9.4	3.4	10.4	6.9
Mar M-302	None	566	40	0.4	5.4	8.4	7.4	5.4
Mar M-302	None	565	55	7.2	9.2	9.2	8.2	8.4
Mar M-302	None	564	70	4.8	5.8	10.8	6.8	7.0
Mar M-302	MDC-9	642	70	5.8	6.8	9.8	10.8	8.3

TABLE 59 (Cont'd)

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Surface Loss, mils: At Location of Average Visual Attack		At Location of Maximum Visual Attack		Mean
X-40	None	573	20	-0.2	2.8	2.8	4.8	2.6
X-40	None	569	25	3.4	4.4	6.4	5.4	4.9
X-40	None	570	55	3.9	7.9	8.9	3.9	6.2
X-40	None	571	85	8.7	14.7	9.7	21.7	13.7
X-40	None	572	115	12.8	6.8	20.8	25.8	16.6
X-40	MDC-9	643	70	3.2	5.2	8.2	4.2	5.2
AiResist 215	None	646	15	3.0	5.0	5.0	4.0	4.2
AiResist 215	None	645	40	2.2	3.2	1.2	6.2	3.2
AiResist 215	None	644	45	1.4	3.9	0.4	3.9	2.4

Notes:

(a) Loss in diameter due to massive oxides and sulfides.

(b) 1 ppm sea salt in air.
0.040 weight per cent sulfur and 0.10 volume % Ethyl CI-2 in fuel.

(*) Localized attack.

TABLE 60

PENETRATION DATA FOR MAXIMUM ATTACK[a] FOR SPECIMENS FROM BASE-LINE[b] TEST

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Maximum Attack, mils: At Location of Average Visual Attack	At Location of Maximum Visual Attack	Maximum Penetration
B-1900	None	7	5	4.5 (O)	13.5 (O)	13.5 (O)
B-1900	None	10	5	-2.2 (B)	5.8 (B)	5.8 (B)
B-1900	None	16	10	6.0 (O)	3.0 (O)	6.0 (O)
B-1900	None	8	15	28.8 (O)	16.8 (B)	28.8 (O)
B-1900	None	13	15	15.1 (O)	15.6 (B)	15.6 (B)
B-1900	None	6	20	24.8 (B)	24.8 (B)	24.8 (B)
B-1900	MDC-1	131	40	4.0 (O)	56.5 (O)	56.5 (O)*
B-1900	MDC-1	130	50	2.4 (B)	9.4 (O)	9.4 (O)*
B-1900	MDC-1	129	60	3.6 (B)	22.6 (O)	22.6 (O)*
B-1900	MDC-1	128	80	28.5 (B)	22.0 (M)	28.5 (B)
B-1900	MDC-9	180	80	3.0 (B)	4.5 (B)	4.5 (B)
B-1900	MDC-9	181	90	3.6 (B)	20.1 (O)	20.1 (O)
B-1900	MDC-9	182	100	5.1 (O)	12.6 (B)	12.6 (B)
B-1900	MDC-9	183	110	5.1 (B)	7.1 (O)	7.1 (O)*
Mar M-246	None	22	5	12.0 (B)	14.5 (B)	14.5 (B)
Mar M-246	None	25	5	9.4 (B)	10.4 (B)	10.4 (B)
Mar M-246	None	31	10	12.5 (B)	13.0 (B)	13.0 (B)
Mar M-246	None	26	15	25.5 (B)	22.0 (M)	25.5 (B)
Mar M-246	None	30	15	15.6 (M)	19.6 (B)	19.6 (B)
Mar M-246	None	24	20	26.0 (B)	26.5 (B)	26.5 (B)
Mar M-246	MDC-1	137	40	3.5 (B)	25.0 (B)	25.0 (B)*
Mar M-246	MDC-1	136	50	6.4 (B)	8.9 (B)	8.9 (B)*
Mar M-246	MDC-1	135	60	7.0 (B)	18.0 (M)	18.0 (M)*
Mar M-246	MDC-1	134	80	12.5 (B)	19.5 (O)	19.5 (O)*
Mar M-246	MDC-9	186	80	4.5 (B)	5.5 (B)	5.5 (B)
Mar M-246	MDC-9	187	90	4.3 (B)	5.8 (B)	5.8 (B)
Mar M-246	MDC-9	188	100	5.3 (M)	10.8 (B)	10.8 (B)
Mar M-246	MDC-9	189	110	5.7 (B)	5.7 (B)	5.7 (B)*
Mar M-200	None	39	5	6.4 (B)	9.4 (B)	9.4 (B)
Mar M-200	None	41	5	9.1 (B)	8.1 (O)	9.1 (B)
Mar M-200	None	46	10	12.0 (M)	26.0 (B)	26.0 (B)
Mar M-200	None	37	15	30.4 (B)	36.4 (M)	30.4 (B)
Mar M-200	None	42	15	19.6 (B)	27.6 (B)	27.6 (B)
Mar M-200	None	43	20	25.6 (B)	35.6 (O)	35.6 (O)

TABLE 60 (Cont'd)

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Maximum Attack, mils: At Location of Average Visual Attack	Maximum Attack, mils: At Location of Maximum Visual Attack	Maximum Attack, mils: Maximum Penetration
Mar M-200	MDC-1	143	40	6.6 (M)	18.1 (B)	18.1 (B)
Mar M-200	MDC-1	142	50	4.9 (B)	25.9 (B)	25.9 (B)
Mar M-200	MDC-1	141	60	25.4 (M)	36.4 (B)	36.4 (B)
Mar M-200	MDC-1	140	80	51.8 (M)	59.3 (M)	59.3 (M)
Mar M-200	MDC-9	192	80	4.5 (B)	12.0 (B)	12.0 (B)*
Mar M-200	MDC-9	193	90	4.1 (B)	5.1 (B)	5.1 (B)*
Mar M-200	MDC-9	194	100	8.1 (0)	8.1 (0)	8.1 (0)*
Mar M-200	MDC-9	195	110	7.5 (B)	11.5 (0)	11.5 (0)*
IN-100	None	52	5	10.4 (B)	12.4 (B)	12.4 (B)
IN-100	None	54	5	6.0 (B)	5.5 (B)	6.0 (B)
IN-100	None	50	10	12.5 (B)	13.5 (B)	13.5 (B)
IN-100	None	53	15	26.4 (B)	25.9 (B)	26.4 (B)
IN-100	None	58	15	22.1 (B)	22.1 (B)	22.1 (B)
IN-100	None	55	20	25.4 (B)	36.4 (B)	36.4 (B)
IN-100	MDC-1	149	40	15.6 (0)	27.6 (0)	27.6 (0)
IN-100	MDC-1	148	50	12.9 (B)	56.4 (B)	56.4 (B)
IN-100	MDC-1	147	60	38.4 (B)	69.4 (B)	69.4 (B)
IN-100	MDC-1	146	80	49.8 (B)	98.3 (B)	98.3 (B)
IN-100	MDC-9	198	45	4.1 (B)	6.1 (B)	6.1 (B)
IN-100	MDC-9	199	55	4.3 (B)	19.8 (B)	19.8 (B)*
IN-100	MDC-9	200	65	17.6 (B)	54.6 (B)	54.6 (B)
IN-100	MDC-9	201	80	18.1 (0)	77.1 (B)	77.1 (B)
Inconel 713C	None	71	10	9.1 (M)	9.6 (M)	9.6 (M)
Inconel 713C	None	67	10	12.9 (M)	10.4 (B)	12.9 (M)
Inconel 713C	None	68	20	19.1 (B)	18.6 (B)	19.1 (B)
Inconel 713C	None	72	20	14.6 (M)	18.6 (M)	18.6 (M)
Inconel 713C	None	66	30	26.9 (B)	25.9 (B)	26.9 (B)
Inconel 713C	None	69	30	33.9 (M)	36.4 (B)	36.4 (B)
Inconel 713C	None	65	40	34.0 (B)	43.0 (B)	43.0 (B)
Inconel 713C	None	70	40	34.5 (B)	45.5 (B)	45.5 (B)
Inconel 713C	MDC-1	152	35	6.8 (B)	10.8 (B)	10.8 (B)
Inconel 713C	MDC-1	159	40	5.5 (0)	10.0 (0)	10.0 (0)
Inconel 713C	MDC-1	153	50	9.6 (M)	31.1 (B)	31.1 (B)
Inconel 713C	MDC-1	158	50	6.4 (B)	16.4 (B)	16.4 (B)
Inconel 713C	MDC-1	154	65	7.0 (0)	46.5 (B)	46.5 (B)
Inconel 713C	MDC-1	157	65	13.8 (M)	14.8 (0)	14.8 (0)
Inconel 713C	MDC-1	155	80	12.8 (0)	57.3 (B)	57.3 (B)
Inconel 713C	MDC-1	156	80	12.5 (0)	26.5 (B)	26.5 (B)

TABLE 60 (Cont'd)

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Maximum Attack, mils: At Location of Average Visual Attack	At Location of Maximum Visual Attack	Maximum Penetration
Inconel 713C	MDC-9	204	165	56.4 (B)	68.4 (B)	68.4 (B)
Inconel 713C	MDC-9	205	165	23.3 (B)	62.3 (B)	62.3 (B)
Udimet 700	None	80	10	6.5 (B)	8.5 (M)	8.5 (M)
Udimet 700	None	82	10	6.9 (B)	8.4 (B)	8.4 (B)
Udimet 700	None	79	20	13.4 (B)	18.9 (B)	18.9 (B)
Udimet 700	None	81	20	11.6 (B)	16.6 (B)	16.6 (B)
Udimet 700	None	76	30	22.4 (B)	23.4 (B)	23.4 (B)
Udimet 700	None	78	30	22.4 (B)	25.9 (B)	25.9 (B)
Udimet 700	None	75	40	28.1 (B)	29.1 (B)	29.1 (B)
Udimet 700	None	77	40	28.0 (B)	42.0 (B)	42.0 (B)
Udimet 700	MDC-1	165	40	4.8 (B)	14.3 (B)	14.3 (B)
Udimet 700	MDC-1	164	50	16.9 (B)	13.9 (B)	16.9 (B)
Udimet 700	MDC-1	163	65	44.5 (B)	36.0 (B)	44.5 (B)
Udimet 700	MDC-1	162	80	24.3 (M)	46.3 (B)	46.3 (B)
Udimet 700	MDC-9	230	75	23.1 (M)	23.1 (O)	23.1 (M)
Udimet 700	MDC-9	209	75	1.6 (B)	6.6 (B)	6.6 (B)
Udimet 700	MDC-9	208	90	11.1 (B)	8.1 (B)	11.1 (B)
Udimet 700	MDC-9	231	90	4.6 (B)	30.1 (B)	30.1 (B)
IN-738	None	88	10	8.0 (B)	8.5 (B)	8.5 (B)
IN-738	None	86	20	9.1 (B)	12.6 (B)	12.6 (B)
IN-738	None	89	30	14.8 (B)	17.8 (B)	17.8 (B)
IN-738	None	87	40	19.9 (B)	19.4 (B)	19.9 (B)
IN-738	None	85	60	36.4 (B)	41.4 (B)	41.4 (B)
IN-738	MDC-1	237	40	4.3 (B)	11.8 (M)	11.8 (M)
IN-738	MDC-1	171	50	16.5 (M)	6.5 (O)	16.5 (M)
IN-738	MDC-1	170	65	6.6 (B)	21.6 (M)	21.6 (M)
IN-738	MDC-1	169	80	4.6 (B)	42.6 (M)	42.6 (M)
IN-738	MDC-1	168	95	14.4 (M)	27.4 (B)	27.4 (B)
IN-738	MDC-9	212	165	24.4 (B)	34.4 (B)	34.4 (B)
IN-738	MDC-9	213	165	16.8 (B)	46.3 (B)	46.3 (B)
Udimet 710	None	96	10	7.1 (B)	9.1 (B)	9.1 (B)
Udimet 710	None	97	20	10.0 (B)	16.0 (B)	16.0 (B)
Udimet 710	None	95	30	15.5 (B)	14.0 (B)	15.5 (B)
Udimet 710	None	94	40	23.1 (B)	36.1 (B)	36.1 (B)
Udimet 710	None	92	60	31.8 (B)	41.8 (B)	41.8 (B)
Udimet 710	None	93	80	56.0 (B)	41.0 (B)	56.0 (B)

TABLE 60 (Cont'd)

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Maximum Attack, mils: At Location of Average Visual Attack	At Location of Maximum Visual Attack	Maximum Penetration
Udimet 710	MDC-1	238	40	5.0 (B)	21.5 (B)	21.5 (B)
Udimet 710	MDC-1	174	50	8.0 (B)	7.5 (O)	8.0 (B)
Udimet 710	MDC-1	175	65	18.1 (B)	26.1 (B)	26.1 (B)
Udimet 710	MDC-1	176	80	28.1 (B)	34.6 (B)	34.6 (B)
Udimet 710	MDC-1	177	95	21.0 (B)	45.0 (B)	45.0 (B)
Udimet 710	MDC-9	217	55	4.1 (B)	12.6 (O)	12.6 (O)
Udimet 710	MDC-9	227	75	2.2 (B)	8.2 (O)	8.2 (O)
Udimet 710	MDC-9	216	90	4.1 (B)	35.6 (B)	35.6 (B)
Udimet 710	MDC-9	226	110	7.5 (O)	18.5 (B)	18.5 (B)
WI-52	None	234	20	7.7 (B)	12.7 (B)	12.7 (B)
WI-52	None	103	25	9.3 (B)	17.3 (B)	17.3 (B)
WI-52	None	102	40	7.5 (M)	13.0 (B)	18.0 (B)
WI-52	None	101	55	14.0 (B)	30.0 (O)	30.0 (O)
WI-52	None	100	70	33.3 (B)	34.8 (B)	34.8 (B)
WI-52	MDC-9	240	70	6.5 (B)	8.5 (B)	8.5 (B)
Mar M-509	None	113	20	7.0 (B)	5.0 (B)	7.0 (B)
Mar M-509	None	106	25	10.3 (B)	8.3 (B)	10.3 (B)
Mar M-509	None	107	40	6.9 (B)	5.9 (B)	6.9 (B)
Mar M-509	None	112	40	11.9 (B)	6.9 (B)	11.9 (B)
Mar M-509	None	108	55	17.1 (B)	10.1 (B)	17.1 (B)
Mar M-509	None	111	55	11.3 (O)	11.8 (O)	11.8 (O)
Mar M-509	None	109	70	18.3 (M)	27.3 (M)	27.3 (M)
Mar M-509	None	110	70	13.2 (M)	16.2 (M)	16.2 (M)
Mar M-509	MDC-9	241	70	5.8 (B)	8.8 (B)	8.8 (B)
Mar M-302	None	235	20	2.3 (B)	5.3 (B)	5.3 (B)
Mar M-302	None	119	25	5.5 (B)	8.5 (B)	8.5 (B)
Mar M-302	None	118	40	6.5 (B)	19.5 (B)	19.5 (B)
Mar M-302	None	117	55	7.8 (B)	9.8 (B)	9.8 (B)
Mar M-302	None	116	70	17.6 (B)	17.6 (B)	17.6 (B)
Mar M-302	MDC-9	242	70	16.5 (B)	21.5 (B)	21.5 (B)*

TABLE 60 (Cont'd)

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Maximum Attack, mils: At Location of Average Visual Attack	At Location of Maximum Visual Attack	Maximum Penetration
X-40	None	236	20	15.1 (B)	5.1 (B)	15.1 (B)
X-40	None	122	25	9.5 (B)	8.5 (B)	9.5 (B)
X-40	None	123	55	29.5 (B)	17.5 (B)	29.5 (B)
X-40	None	124	85	25.6 (B)	31.6 (B)	31.6 (B)
X-40	None	125	115	45.9 (B)	26.9 (B)	45.9 (B)
X-40	MDC-9	243	70	8.0 (B)	8.0 (B)	8.0 (B)
AiResist 215	None	246	15	4.9 (B)	5.9 (B)	5.9 (B)
AiResist 215	None	245	40	6.0 (O)	9.0 (B)	9.0 (B)
AiResist 215	None	244	45	7.1 (B)	11.1 (B)	11.1 (B)

Notes:

(a) Loss in diameter due to all forms of oxidation and sulfidation.

(b) 1 ppm sea salt in air.
0.040 weight per cent sulfur in fuel.

(*) Localized attack.

(B) Attack on both sides of specimen.

(M) Attack mostly on one side of specimen.

(O) Attack on one side of specimen.

TABLE 61

PENETRATION DATA FOR MAXIMUM ATTACK[(a)] FOR SPECIMENS FROM FUEL-ADDITIVE[(b)] TEST

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Maximum Attack, mils: At Location of Average Visual Attack	Maximum Attack, mils: At Location of Maximum Visual Attack	Maximum Attack, mils: Maximum Penetration
B-1900	None	501	5	5.1 (B)	5.6 (B)	5.6 (B)
B-1900	None	503	5	7.5 (M)	6.0 (B)	7.5 (M)
B-1900	None	505	10	11.8 (M)	11.8 (B)	11.8 (B)
B-1900	None	502	15	19.6 (B)	19.6 (B)	19.6 (B)
B-1900	None	504	15	18.4 (B)	19.9 (B)	19.9 (B)
B-1900	None	500	20	32.6 (B)	35.1 (B)	35.1 (B)
B-1900	MDC-1	577	40	3.1 (B)	6.1 (B)	6.1 (B)
B-1900	MDC-1	576	50	4.3 (0)	7.3 (B)	7.3 (B)
B-1900	MDC-1	575	60	3.5 (B)	4.5 (0)	4.5 (0)
B-1900	MDC-1	574	80	5.0 (B)	8.0 (0)	8.0 (0)
B-1900	MDC-9	612	80	4.9 (B)	5.9 (B)	5.9 (B)
B-1900	MDC-9	613	90	4.0 (B)	5.0 (B)	5.0 (B)
B-1900	MDC-9	614	100	4.5 (B)	14.0 (B)	14.0 (B)
B-1900	MDC-9	615	110	5.1 (B)	5.6 (B)	5.6 (B)
Mar M-246	None	506	5	9.1 (B)	14.1 (B)	14.1 (B)
Mar M-246	None	508	5	8.3 (B)	11.3 (B)	11.3 (B)
Mar M-246	None	510	10	16.7 (B)	20.2 (B)	20.2 (B)
Mar M-246	None	509	15	23.4 (B)	25.9 (B)	25.9 (B)
Mar M-246	None	511	15	31.5 (B)	42.0 (B)	42.0 (B)
Mar M-246	None	507	20	34.5 (B)	41.5 (B)	41.5 (B)
Mar M-246	MDC-1	581	40	7.3 (B)	5.3 (B)	7.3 (B)
Mar M-246	MDC-1	580	50	4.4 (B)	16.4 (B)	16.4 (B)
Mar M-246	MDC-1	579	60	4.5 (B)	7.5 (B)	7.5 (B)
Mar M-246	MDC-1	578	80	5.8 (B)	8.8 (B)	8.8 (B)
Mar M-246	MDC-9	616	80	1.0 (B)	5.0 (B)	5.0 (B)
Mar M-246	MDC-9	617	90	4.8 (M)	9.8 (B)	9.8 (B)
Mar M-246	MDC-9	618	100	3.8 (B)	4.8 (B)	4.8 (B)
Mar M-246	MDC-9	619	110	4.1 (B)	4.1 (B)	4.1 (B)*
Mar M-200	None	513	5	17.4 (B)	16.4 (M)	17.4 (B)
Mar M-200	None	514	5	10.1 (B)	11.1 (B)	11.1 (B)
Mar M-200	None	517	10	14.5 (B)	17.5 (B)	17.5 (B)
Mar M-200	None	512	15	17.2 (B)	26.2 (B)	26.2 (B)
Mar M-200	None	515	15	25.9 (B)	28.9 (B)	28.9 (B)
Mar M-200	None	516	20	30.9 (B)	35.9 (B)	35.9 (B)

TABLE 61 (Cont'd)

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Maximum Attack, mils: At Location of Average Visual Attack	At Location of Maximum Visual Attack	Maximum Penetration
Mar M-200	MDC-1	585	40	6.8 (B)	4.8 (B)	6.8 (B)
Mar M-200	MDC-1	584	50	3.3 (B)	7.3 (B)	7.3 (B)
Mar M-200	MDC-1	583	60	5.1 (0)	6.1 (0)	6.1 (0)
Mar M-200	MDC-1	582	80	8.2 (B)	9.2 (B)	9.2 (B)
Mar M-200	MDC-9	620	80	2.6 (B)	4.6 (B)	4.6 (B)*
Mar M-200	MDC-9	621	90	0.9 (B)	4.9 (B)	4.9 (B)*
Mar M-200	MDC-9	622	100	-0.2 (B)	-1.2 (B)	-0.2 (B)*
Mar M-200	MDC-9	623	110	3.2 (B)	4.2 (B)	4.2 (B)*
IN-100	None	519	5	9.2 (B)	12.2 (B)	12.2 (B)
IN-100	None	521	5	6.4 (B)	11.4 (B)	11.4 (B)
IN-100	None	518	10	14.8 (B)	15.8 (B)	15.8 (B)
IN-100	None	520	15	25.0 (B)	24.0 (B)	25.0 (B)
IN-100	None	523	15	23.6 (B)	30.6 (B)	30.6 (B)
IN-100	None	522	20	30.0 (B)	31.0 (B)	31.0 (B)
IN-100	MDC-1	589	40	4.0 (B)	7.0 (B)	7.0 (B)*
IN-100	MDC-1	588	50	12.9 (0)	36.9 (0)	36.9 (0)
IN-100	MDC-1	587	60	22.8 (B)	87.8 (B)	87.8 (B)
IN-100	MDC-1	586	80	62.7 (B)	62.7 (B)	62.7 (B)
IN-100	MDC-9	624	45	5.5 (B)	5.5 (B)	5.5 (B)*
IN-100	MDC-9	625	55	4.2 (B)	5.2 (B)	5.2 (B)
IN-100	MDC-9	626	65	3.7 (B)	6.7 (B)	6.7 (B)
IN-100	MDC-9	627	80	12.8 (B)	36.8 (B)	36.8 (B)
Inconel 713C	None	530	10	11.4 (B)	15.4 (B)	15.4 (B)
Inconel 713C	None	525	10	13.5 (B)	29.5 (B)	29.5 (B)
Inconel 713C	None	527	20	19.0 (B)	23.0 (B)	23.0 (B)
Inconel 713C	None	531	20	22.3 (B)	23.3 (B)	23.3 (B)
Inconel 713C	None	526	30	36.7(B)	38.7 (B)	38.7 (B)
Inconel 713C	None	528	30	34.7 (B)	43.7 (B)	43.7 (B)
Inconel 713C	None	524	40	21.9 (B)	50.9 (B)	50.9 (B)
Inconel 713C	None	529	40	12.9 (B)	50.9 (B)	50.9 (B)
Inconel 713C	MDC-1	590	35	7.6 (B)	5.6 (B)	7.6 (B)
Inconel 713C	MDC-1	597	40	-0.2 (B)	6.8 (B)	6.8 (B)
Inconel 713C	MDC-1	591	50	4.9 (B)	6.9 (B)	6.9 (B)
Inconel 713C	MDC-1	596	50	7.3 (B)	8.3 (B)	8.3 (B)
Inconel 713C	MDC-1	592	65	7.1 (B)	8.1 (B)	8.1 (B)
Inconel 713C	MDC-1	595	65	6.1 (B)	38.1 (B)	38.1 (B)*
Inconel 713C	MDC-1	593	80	23.6 (B)	14.6 (B)	23.6 (B)
Inconel 713C	MDC-1	594	80	6.3 (0)	8.3 (0)	8.3 (0)

TABLE 61 (Cont'd)

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Maximum Attack, mils: At Location of Average Visual Attack	At Location of Maximum Visual Attack	Maximum Penetration
Inconel 713C	MDC-9	628	165	7.0 (B)	15.0 (B)	15.0 (B)*
Inconel 713C	MDC-9	629	165	7.7 (B)	13.7 (O)	13.7 (O)
Udimet 700	None	537	10	6.3 (B)	9.3 (B)	9.3 (B)
Udimet 700	None	538	10	9.1 (B)	10.1 (B)	10.1 (B)
Udimet 700	None	536	20	17.0 (B)	21.0 (B)	21.0 (B)
Udimet 700	None	539	20	24.1 (B)	20.1 (B)	24.1 (B)
Udimet 700	None	533	30	21.5 (B)	29.5 (B)	29.5 (B)
Udimet 700	None	535	30	28.8 (B)	39.8 (B)	39.8 (B)
Udimet 700	None	532	40	36.5 (B)	35.5 (B)	36.5 (B)
Udimet 700	None	534	40	29.7 (B)	28.7 (B)	29.7 (B)
Udimet 700	MDC-1	598	40	16.4 (B)	4.4 (B)	16.4 (B)
Udimet 700	MDC-1	599	50	5.5 (B)	6.5 (M)	6.5 (M)
Udimet 700	MDC-1	600	65	6.3 (B)	7.3 (M)	7.3 (M)
Udimet 700	MDC-1	601	80	14.1 (B)	16.1 (B)	16.1 (B)
Udimet 700	MDC-9	633	75	7.4 (B)	8.4 (B)	8.4 (B)*
Udimet 700	MDC-9	630	75	5.4 (B)	8.4 (B)	8.4 (B)
Udimet 700	MDC-9	631	90	12.3 (B)	20.3 (B)	20.3 (B)
Udimet 700	MDC-9	632	90	4.8 (B)	10.8 (B)	10.8 (B)
IN-738	None	541	10	10.4 (B)	16.4 (B)	16.4 (B)
IN-738	None	542	20	20.0 (B)	20.0 (B)	20.0 (B)
IN-738	None	544	30	32.1 (B)	26.1 (B)	32.1 (B)
IN-738	None	543	40	28.2 (B)	36.2 (B)	36.2 (B)
IN-738	None	540	60	60.6 (B)	83.6 (B)	83.6 (B)
IN-738	MDC-1	606	40	5.8 (B)	11.8 (B)	11.8 (B)
IN-738	MDC-1	602	50	5.5 (B)	6.5 (B)	6.5 (B)
IN-738	MDC-1	603	65	5.7 (B)	5.7 (B)	5.7 (B)
IN-738	MDC-1	604	80	6.4 (B)	8.4 (B)	8.4 (B)
IN-738	MDC-1	605	95	8.5 (B)	12.5 (O)	12.5 (O)
IN-738	MDC-9	634	165	4.9 (B)	6.9 (B)	6.9 (B)*
IN-738	MDC-9	635	165	3.4 (B)	57.4 (B)	57.4 (B)
Udimet 710	None	548	10	7.5 (B)	15.5 (B)	15.5 (B)
Udimet 710	None	550	20	13.8 (B)	15.8 (B)	15.8 (B)
Udimet 710	None	549	30	13.7 (B)	8.7 (B)	13.7 (B)
Udimet 710	None	547	40	23.6 (B)	54.6 (B)	54.6 (B)
Udimet 710	None	545	60	59.8 (B)	55.8 (B)	59.8 (B)
Udimet 710	None	546	80	68.1 (B)	116.1 (B)	116.1 (B)

TABLE 61 (Cont'd)

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Maximum Attack, mils: At Location of Average Visual Attack	At Location of Maximum Visual Attack	Maximum Penetration
Udimet 710	MDC-1	611	40	6.1 (B)	16.1 (M)	16.1 (M)
Udimet 710	MDC-1	607	50	3.4 (B)	5.4 (B)	5.4 (B)*
Udimet 710	MDC-1	608	65	8.1 (M)	6.1 (B)	8.1 (M)*
Udimet 710	MDC-1	609	80	9.1 (B)	8.1 (B)	9.1 (B)*
Udimet 710	MDC-1	610	95	22.3 (B)	31.3 (B)	31.3 (B)
Udimet 710	MDC-9	636	55	6.2 (B)	7.2 (B)	7.2 (B)
Udimet 710	MDC-9	639	75	8.1 (O)	10.1 (O)	10.1 (O)
Udimet 710	MDC-9	637	90	19.9 (B)	23.9 (B)	23.9 (B)
Udimet 710	MDC-9	638	110	4.4 (B)	8.4 (B)	8.4 (B)
WI-52	None	554	20	3.2 (B)	11.2 (B)	11.2 (B)
WI-52	None	555	25	12.6 (B)	17.6 (B)	17.6 (B)
WI-52	None	553	40	11.0 (B)	16.0 (B)	16.0 (B)
WI-52	None	552	55	6.0 (B)	13.0 (B)	13.0 (B)
WI-52	None	551	70	21.3 (B)	19.3 (B)	21.3 (B)
WI-52	MDC-9	640	70	10.7 (M)	14.7 (B)	14.7 (B)
Mar M-509	None	563	20	2.6 (B)	8.6 (B)	8.6 (B)
Mar M-509	None	556	25	4.1 (B)	6.1 (B)	6.1 (B)
Mar M-509	None	557	40	8.6 (B)	19.6 (B)	19.6 (B)
Mar M-509	None	562	40	7.0 (O)	19.0 (O)	19.0 (O)
Mar M-509	None	558	55	14.0 (B)	14.0 (B)	14.0 (B)
Mar M-509	None	561	55	2.8 (B)	7.8 (B)	7.8 (B)
Mar M-509	None	559	70	18.0 (B)	28.0 (B)	28.0 (B)
Mar M-509	None	560	70	17.5 (B)	16.5 (B)	17.5 (B)
Mar M-509	MDC-9	641	70	6.6 (B)	5.6 (B)	6.6 (B)
Mar M-302	None	568	20	3.3 (B)	3.3 (B)	3.3 (B)
Mar M-302	None	567	25	9.4 (B)	10.4 (B)	10.4 (B)
Mar M-302	None	566	40	5.4 (B)	8.4 (B)	8.4 (B)
Mar M-302	None	565	55	9.2 (B)	9.2 (B)	9.2 (B)
Mar M-302	None	564	70	13.8 (B)	13.8 (B)	13.8 (B)
Mar M-302	MDC-9	642	70	7.8 (B)	10.8 (B)	10.8 (B)

TABLE 61 (Cont'd)

Superalloy	Coating	Spec. No.	Exposure Time, hrs	Maximum Attack, mils: At Location of Average Visual Attack	At Location of Maximum Visual Attack	Maximum Penetration
X-40	None	573	20	12.8 (B)	9.8 (B)	12.8 (B)
X-40	None	569	25	13.4 (B)	7.4 (B)	13.4 (B)
X-40	None	570	55	20.9 (M)	34.9 (B)	34.9 (B)
X-40	None	571	85	40.7 (B)	28.7 (B)	40.7 (B)
X-40	None	572	115	27.3 (M)	58.8 (B)	58.8 (B)
X-40	MDC-9	643	70	8.2 (B)	15.2 (B)	15.2 (B)
AiResist 215	None	646	15	5.0 (B)	5.0 (B)	5.0 (B)
AiResist 215	None	645	40	3.2 (B)	6.2 (B)	6.2 (B)
AiResist 215	None	644	45	6.9 (B)	5.9 (B)	6.9 (B)

Notes:

(a) Loss in diameter due to all forms of oxidation and sulfidation.

(b) 1 ppm sea salt in air.
0.040 weight per cent sulfur and 0.10 volume % Ethyl CI-2 in fuel.

(*) Localized attack.

(B) Attack on both sides of specimen.

(M) Attack mostly on one side of specimen.

(O) Attack on one side of specimen.

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	Department of the Navy Naval Aeronautical Engine Department Philadelphia, Pennsylvania 19112

13. ABSTRACT This investigation is concerned with the effects of Ethyl Corporation's CI-2 smoke-abatement additive on a wide variety of superalloys and superalloy coating systems relative to deposit accumulations and hot-corrosion attack. Specimens of 12 superalloys and 20 coated superalloys involving Misco MDC-1 and MDC-9 aluminum-type coatings were exposed in separate tests using a JP-5 fuel containing 0.04 wt % sulfur and an aliquot sample of this fuel containing 0.1 volume per cent of methyl-cyclopentadienyl-manganese-tricarbonyl (Ethyl CI-2) for comparable periods of time between 5 and 165 hours. All specimens were exposed at 15 atmospheres combustor pressure with gas temperatures and velocity at the specimens cycled from 1000-2000F and 163-275 ft/sec by control of fuel flow to simulate conditions in the turbine section of a turbine engine. Sea water was added at a concentration of 1 ppm of sea salt in air to simulate a marine environment. Effects of CI-2 on turbine-blade deposits were estimated from chemical and physical analyses, visual appearances, and statistical analyses of differential weight measurement (mg/cm^2). Methods for evaluating the effects of CI-2 on hot corrosion relied on visual observations, metallographic examination, and statistical analyses based on measurements of metal weight-loss (mg/cm^2), surface-loss (mils), and maximum penetration of corrosion products (mils).

In general CI-2 in the fuel tended to increase hot corrosion of bare superalloys and tended to decrease hot corrosion of coated superalloys. For all turbine-blade materials, CI-2 in the fuel was found to increase deposit accumulations seriously. These data indicate that the use of this additive on a continuous or extended basis could reduce engine performance.

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OXIDATION						
SULFIDATION						
SMOKE EMISSION						
SMOKE SUPPRESSANT ADDITIVE						
ETHYL CI-2 ADDITIVE						
TURBINE BLADES						
ALLOY						
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